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Relative abundance, population structure, and stock status of blue cod off south Otago in 2013. Estimates of pot catchability and size selectivity.

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This report describes the results of the 2013 south Otago blue cod (*Parapercis colias*) potting survey. This is the second random site allocation potting survey to be undertaken in the time series for south Otago. Flown video transects were also done prior to potting at six survey sites in an evaluation of the size selectivity and catchability of survey pots.

The 2013 potting survey used a two-phase stratified random site design with six sites per stratum randomly allocated for phase 1. Between 5 April to 17 May 2013, forty potting sites were surveyed (6 pots per site = 240 pot lifts) from six strata off south Otago. During phase 1, 216 pot lifts were completed (90%) with 24 in phase 2. The total blue cod catch was 1287 kg, consisting of 2397 blue cod. Most fish had gonads in the early maturing stages, but considerably more offshore fish had spent gonads indicating spatial variability in the conclusion of spawning.

Stratum catch rates for blue cod of all sizes ranged from 0.8 to 13.7 $kg.pot^{-1}$ with an overall mean catch rate of 6.24 $kg.pot^{-1}$ and coefficient of variation (CV) of 19.9%. Stratum catch rates of legal size blue cod (30 cm and over) ranged from 0.7 to 12.8 $kg.pot^{-1}$, with an overall mean catch rate of 5.1 $kg.pot^{-1}$ and CV of 23.0%. Catch rates were highest off the Toko river mouth in open water between 50 m and 80 m deep, and lowest along the coast of the Otago Peninsula. Thirty-seven percent of blue cod caught from five inshore strata (i.e., below 80 m depth) exceeded the minimum legal size (MLS=30 cm and over), but 72% of blue cod from the offshore stratum (i.e., over 100 m depth) exceeded the MLS.

Total length ranged from 13 to 55 cm among the five inshore strata, and from 12 to 53 cm in the offshore stratum. Length frequency distributions show unusually large numbers of small blue cod (18–24 cm) at the four most southern inshore strata (excluding the Otago Peninsula). Inshore strata also had similar size structures with few blue cod over 45 cm, except for the southern inshore 50–80 m depth stratum where larger blue cod were found. The length frequency distributions from the offshore stratum had proportionately fewer fish below 30 cm and a relatively higher proportion of fish over 45 cm. Males were larger than females in all strata and overall mean length of inshore strata was 31.4 cm for males and 24.1 cm for females, while the mean length of the offshore stratum was 37.9 cm for males and 32.1 cm for females. The overall sex ratio for inshore strata was skewed in favour of males for both all fish 1:0.8 (M:F) and legal size fish (1:0.3). However, the offshore stratum sex ratio was skewed in favour of females for both all fish (1:1.3) and legal size fish (1:1.1).

Otoliths were prepared and read for 176 males and 129 females from the five inshore strata, and 89 males and 111 females from the offshore stratum. These were used to construct separate age-length keys for inshore and offshore areas, and applied to the scaled length frequency distributions to estimate the population age structure for each sex. Inshore ages ranged from 2 to 32 years, but most fish were between 3 and 11 years for males and 3 and 6 years for females. Mean age inshore was 8.4 years for males and 6.1 years for females. Offshore ages ranged from 1 to 29 years, but most fish were between 7 and 15 years for males and 8 and 12 years for females. Mean age offshore was 11.2 years for males and 9.9 years for females.

Total mortality estimates (Z) for age at recruitment from 5 to 10 years ranged between 0.18 and 0.25 for the inshore strata, and between 0.13 and 0.21 for the offshore stratum. The subsequent spawner (biomass) per recruit ratio (SPR) using the default M value of 0.14 was 57% for the inshore strata and 74% for the offshore stratum. These values indicate that at the current level of fishing mortality the expected contribution to the spawning biomass over the lifetime of an average recruit has been reduced to 57% (inshore) and 74% (offshore) of the contribution in the absence of fishing. These levels of exploitation (F) are well within the Ministry of Fisheries target reference point of $F_{45\%}$ for blue cod, and indicates that the current level of fishing is acceptable for all surveyed areas of south Otago.

Survey comparison
Since the initial three strata random site potting survey of south Otago in 2010 (18 sites, 108 pot lifts), the overall catch rates for all and legal sized blue cod have increased by 42% and 76%, respectively, among equivalent strata of the 2013 survey. There was an increase in catch rates in all strata, but the overall increase in catch rates was driven mainly by the southern inshore stratum (50–80 m depth) off the Toko river mouth. The overall CVs for the 2013 survey catch rates were marginally higher than the overall CVs from the 2010 survey.

The percentage of blue cod caught that exceeded the MLS in the three comparable strata of the 2013 survey (49%) had more than doubled since the 2010 survey (21%), and the overall mean length had increased by 8.6 cm for males and 7.6 cm for females. While overall sex ratio changed little between surveys, male dominance had increased along the coast of the Otago Peninsula and decreased to the point of female dominance in the deep water offshore stratum. The overall mean age increased by 0.6 years for males and 0.3 years for females between the surveys and Z estimates were lower in 2013. The overall SPR (M=0.14) increased 22% between surveys to a level (61%) that suggests fishing pressure is adequately constrained in south Otago.

Catchability and size selectivity of survey pots
Four to five flown drop underwater video (DUV) transects were conducted at six sites, immediately prior to setting the type 2 survey pots (n=6), for comparisons of size selectivity and catchability. The DUV system surveyed a total area of 46 100 m^2 and 2777 blue cod (5–50 cm) were recorded. Pots subsequently caught 478 blue cod (15–54 cm). Compared to the DUV, the pots caught proportionately more blue cod over 30 cm and less under 19 cm. Although only six sites were surveyed, the estimated density of blue cod from video transects had a much stronger relationship with pot catches in Otago than in other survey areas, suggesting that catchability may be spatially variable.

Habitat Preferences of blue cod
The ratio of fish-dependent and fish-independent video habitat observations revealed that blue cod were observed disproportionately more often on shell grit/gravel, sand/shell grit/gravel and sand/shell grit with horse mussels and/or some form of sponge. Horse mussels and sponge were also the most common habitats observed in the benthic environment surveyed in Otago these habitats appear to be particularly important to small blue cod, and are the likely to be the driver of some of the highest abundance estimates of blue cod ever recorded.

1 INTRODUCTION

Blue cod (*Parapercis colias*) is a particularly desirable finfish caught easily by line or pot and is the most frequently landed recreational species in the South Island (Ministry for Primary Industries 2017). Blue cod is also an important species for Maori customary fishers in all areas, but the catch is unknown. Tagging shows that most blue cod have a restricted home range (Rapson 1956, Mace & Johnston 1983, Mutch 1983, Carbines & McKenzie 2001, 2004), and stocks of this species largely consist of many independent sub-stocks within each Fisheries Management Area (FMA) (Carbines 2004a). Due to this philopatric behaviour, blue cod may be especially susceptible to localised depletion within subareas of FMAs, and in response to local fishing pressure, recreational daily bag limits vary within South Island FMAs (Ministry for Primary Industries 2017).

Commercial blue cod catch along the east coast of the South Island (BCO 3) has been constrained by a relatively small total allowable commercial catch (163 t), and accounts for only 7% of BCO quota nationally (Ministry for Primary Industries 2017). However, BCO 3 has been overcaught by up to 20 t in most years since 2003–04 (Ministry of Fisheries 2017). Estimates of the recreational blue cod catch for BCO 3 have been highly variable (101–752 t), but the most recent estimate in 2012 (101 t) suggests that BCO 3 is a shared fishery with similar amounts of harvest from the commercial and non-commercial sectors.

Within BCO 3 there are currently three areas where recreational minimum legal size (MLS) and daily bag limits have been varied (i.e., Otago, north Canterbury and Kaikoura; Ministry for Primary Industries 2017). However, unlike north Canterbury and Kaikoura, neither the MLS (30 cm) nor the daily bag limit (30 fish) has been altered within the Otago area (Ministry for Primary Industries 2017). The rocky area off south Otago supporting blue cod is not extensive, but consists of both inshore and offshore areas (See Figure 1). For some time recreational fishers have been concerned about reported declines in catches and sizes of blue cod in the Otago area, and an increase in the number of Canterbury based private recreational and charter boats operating in the area has been blamed (South Marine Recreational Fishers Advisory Group pers. comm.). Local recreational fishers are concerned that lowering the blue cod bag limit down to 10 per day in north Canterbury, 6 per day in Kaikoura, and 2 per day in the Marlborough Sounds (BCO 7), has resulted in a transfer of fishing effort into the Otago region.

Ministry for Primary Industries potting surveys

To monitor South Island blue cod populations, the Ministry for Primary Industries undertakes a quadrennial series of potting surveys to generate relative biomass estimates in key recreational fisheries within all three South Island FMA. These include the Marlborough Sounds, Kaikoura, Motunau, Banks Peninsula, north and south Otago, Dusky Sound, Foveaux Strait, and Paterson Inlet (Ministry for Primary Industries 2017). These surveys provide relative abundance indices as well as information on population size/age structure, mortality estimates, and sex ratio used to monitor blue cod stocks. In addition to catch rate information, monitoring age structure provides a possible means of evaluating the response of a population to changes in fishing pressure. Otoliths collected during potting surveys are used to calculate the age structure of blue cod in different areas of the South Island. Subsequent estimates of total mortality (Z) for each survey are based on catch curve analysis (Ricker 1975) of the age distributions derived specifically for each survey; thus it is possible to determine stock status using an MSY-related proxy. For blue cod there is insufficient information to estimate B_{MSY} for those populations supporting local recreational fisheries - in part because recreational catches have not been estimated reliably, and most likely represent a significant proportion of the total catch. F_{MSY} is a more appropriate reference point for managing such blue cod populations, and the most widely used proxy for F_{MSY} currently is from spawner per recruit analyses ($F_{\%SPR}$). Hence, we are interested in where fishing mortality, derived from the catch curve analysis (Z) and estimates of M, lies in relation to the recommended $F_{45\%SPR}$ reference point for blue cod. This is documented in the Ministry of Fisheries 'Operational Guidelines for New Zealand's Harvest Strategy Standard' (Ministry of Fisheries 2011).

South Otago 2010 potting survey

The 2010 south Otago potting survey was the first in the time series for this area. However, the 2010 survey design was experimental, comparing random with fixed site sampling, and also directed with systematic pot placement (Beentjes & Carbines 2011). Thirty six sites were successfully surveyed from three strata (strata 1, 3, and 6 in Figure 1) off Otago Peninsula and Toko river mouth between April and June 2010. Within each stratum, six fixed and six random sites were sampled, and at each site six pots were set, three using directed pot placement and three using systematic pot placement, resulting in 108 pots from each placement method and 216 overall. There was no phase 2 component to the survey. A total of 2573 blue cod (1349 kg) was taken on the 2010 south Otago survey. Blue cod comprised 97% by weight of the catch of all species on the survey. The overall sex ratio (M:F) was 1:0.4 for all blue cod, and 1:0.2 for fish 30 cm and over. Both length distribution and catch rates were substantially different between fixed and random sites and they were analysed separately. However, there were no significant differences between pot placement methods in south Otago, so data from all six pots per site were combined in the analyses. The blue cod examined were not spawning at the time of the survey. Otoliths were prepared and read for 324 males and 243 females and these were used to construct a single age-length-key for the survey, applied to both fixed and random sites independently (Beentjes & Carbines 2011).

Blue cod caught from fixed sites were on average larger than those from random sites, and this resulted in lower Z estimates, and higher F%SPR values in fixed sites. The overall catch rate from fixed sites was more than double that from the random sites, and survey precision for random sites was comparable to those for fixed sites (Beentjes & Carbines 2011). A total of 434 kg was taken from random sites, and the overall sex ratio (M:F) was 1:0.5 for all blue cod at random sites. Overall mean catch rates were 4.4 kg.pot^{-1} (CV 17.8%) for all blue cod and 2.9 kg.pot^{-1} (CV 22.5%) for recruited blue cod (30 cm and over). Size ranged from 16 to 59 cm for males and 11 to 49 cm for females. The scaled length frequency distributions for males and females were unimodal with mean lengths of 29.0 and 23.7 cm respectively. Overall 21% of blue cod were of minimum legal size (30 cm and over). Length frequency distributions for both sexes were also strongly skewed to the right. The estimated population age distributions were generally unimodal with the main peak at about six years for males and four years for females. Most fish (males and females) were between four and eight years old. Mean ages were 7.8 years and 6.0 years for males and females respectively. The mortality estimates (Z) are between 0.26 and 0.28 (0.28 for age at full recruitment = 6 years). Based on the default M of 0.14, the F%SPR was estimated at $F_{39.4\%}$ indicating that the expected contribution to the spawning biomass over the lifetime of an average recruit has been reduced to 39% of the contribution in the absence of fishing (Beentjes & Carbines 2011).

Pot catches verses underwater observations

The basic premise of potting surveys as long term monitoring programmes is that this passive capture method provides estimates of the relative abundance and size structure of blue cod populations within the survey areas.

However, a review of the blue cod potting programme recommended that this premise requires further validation (Stephenson et al. 2009). Different methods have different size selectivity and catch rates, and size composition from potting can differ both between pot types (Beentjes & Carbines 2012, Carbines & Beentjes 2012, Carbines & Haist 2017b) and with other methods such as line fishing (Carbines 1999, 2008).

Pot catches have a "weak" and highly variable and a largely unexplained relationship with counts from diver transects (Cole et al. 2001), and continuous video recordings of blue cod entries and exits from pots show that less than 8% of approaches lead to entries, and that local topography can constrain pot entries in some situations (Cole et al. 2004). Comparisons of remote flown video transects done immediately prior to potting also show a higher proportion of small blue cod observed than were caught, and the relationship between pot catch and video counts (i.e., catchability) has often been poor and highly variable over time and/or location (Beentjes & Carbines 2012, Carbines & Beentjes 2012, Carbines & Haist 2014, 2017a, 2017b). To further investigate the relationship between potting survey catch rates and size structure with direct *in situ* video observations of blue cod, the 2013 south Otago potting survey employed fish counts from five replicate drop underwater video (DUV) flown transects immediately prior to setting six pots at a target of 10 survey sites.

Overall objective

1. To estimate relative abundance, maturity state, sex ratio, and age structure of blue cod (*Parapercis colias*) off south Otago.

Specific objectives

1. To undertake a potting survey off south Otago to estimate relative abundance, size- and age at-maturity, sex ratio and collect otoliths from pre-recruited and recruited blue cod.

2. To analyse biological samples collected from this potting survey.

3. To determine stock status of blue cod populations in this area, and compare with other previous surveys in this area and other areas.

4. To undertake a Dropped Underwater Video (DUV) survey concurrently with the potting survey to provide comparative estimates of biomass.

2 METHODS

In this report we use only the terms and methods defined in the blue cod potting survey manual (Beentjes & Francis 2011), but note that surveys carried out before this manual was written, may have used different and inconsistent terminology (see Appendix 1).

2.1 Timing

The previous potting survey for the south Otago area was done in autumn, but protracted by bad weather from 21 April to 5 June 2010 (Beentjes & Carbines 2011). To continue the random site survey time series for south Otago with minimal temporal (seasonal) variability between surveys, the 2013 south Otago potting survey was also done in autumn, but done from 5 April to 17 May 2013 due to mainly calm weather.

2.2 Survey area

Prior to the 2010 fixed and random site potting surveys, the south Otago survey area was defined after discussions with local recreational and commercial fishers. Fishers were given charts of the area and asked to mark discrete locations around south Otago where blue cod are commonly caught. Based on this the survey area was divided into five inshore strata (two coastal strata and three 50–80 m depth strata) and one offshore stratum (100–200 m depth) at the head of several canyons (Figure 1). The area (km^2) of each stratum was taken as a proxy of available habitat for blue cod.

2.3 Survey design

The 2013 south Otago random site potting survey used a two-phase stratified design, using six pots per site (Table 1) and sites at least 1000 m apart (Figure 1). Six sites per stratum (n=36 sites, 216 pot lifts) were allocated to six strata for phase one (Table 1), and an additional four sites (24 pot lifts) were allocated in phase two (10.4%).

Allocation of phase 2 sites was based on the mean catch rate (kg.pot^{-1}) of all blue cod per stratum and optimised using the "area mean squared" method of Francis (1984). In this way, phase 2 sites were assigned iteratively to the stratum in which the expected gain is greatest, where expected gain is given by:

$$expected\ gain_i = area_i^{\ 2}\ mean_i^{\ 2} / (n_i(n_i+1)) \qquad (1)$$

where for the *i*th stratum, $mean_i$ is the mean catch rate, $area_i$ is the area, and n_i is the number of sets in phase 1. In the iterative application of this equation, n_i is incremented by 1 each time a phase 2 set is allocated to stratum *i*. Pots were always allocated in groups of six which equates to one set.

2.4 Vessels and gear

The 2013 south Otago potting surveys were conducted from F.V. *Triton*, a local commercial vessel equipped to set and lift rock lobster and blue cod pots. The vessel was charted by Saltwater Science Ltd and skippered by the owner Mr Neil McDonald. The vessel specifications are: 11 m length, 4 m breadth, 12 t, wooden monohull, powered by a 120 hp diesel engine with propeller propulsion. The trip code for the survey was TRI1302.

Six custom designed and built cod pots were used to conduct the surveys. Pot specifications were: length 1200 mm, width 900 mm, depth 500 mm, 30 mm diameter synthetic inner mesh, 50 mm cyclone wire outer mesh, entrances 4 (Pot Plan 2 in Beentjes & Francis 2011). Pots were marked with a number from 1 to 6, and baited with paua guts in "snifter pottles". Bait was topped up after every lift and replaced each day. The same pot design and bait type were used in all previous South Island blue cod potting survey time series except Marlborough Sounds, where the pots used are of different dimensions and construction (Pot Plan 1 in Beentjes & Francis 2011).

A high-performance, 3-axis (3D) acoustic doppler current profiler (RDI - 1200 kHz) was deployed at each site. The ADCP records current flow and direction in 5 m depth bins.

2.5 Sampling methods

The ADCP was initially deployed at the random point generated, and around this central point, six pots were set sequentially in a fixed hexagon pattern with each point (pot) approximately 300 m from the centre and 300 m from adjacent pots. The six pots were set blind (i.e., not targeted by sonar) in the fixed grid pattern determined from an initial starting point approximately 300 m north of the random site location occupied by the ADCP.

Pots were left to fish (soak) for approximately one hour during daylight hours. After each site was completed (six pot lifts) the next closest site in the stratum was sampled. While it was not logistically possible to standardise for time of day or tides, each stratum was usually surveyed throughout the day, collectively giving each stratum roughly equal exposure to all daily tidal and time regimes. The order that strata were surveyed depended on the prevailing weather conditions, as exposed strata could only be surveyed during calm conditions.

As each pot was set, a record was made on customised forms (See Beentjes & Francis 2011) of pot number, latitude and longitude, depth, time of day, and standard trawl survey physical oceanographic data, including wind direction, wind force, air temperature, air pressure, cloud cover, sea condition, sea colour, swell height, swell direction, bottom type, bottom contour, sea surface temperature, sea bottom temperature, wind speed, and water visibility (secchi depth). The ADCP was deployed at the centre of each site to record current speed and direction throughout the pot sets.

After one hour, pots were lifted aboard using the vessel's hydraulic pot lifter, emptied, and the contents sorted by species. Total weight per pot was recorded for each species to the nearest 10 g using 10 kg

Merel motion compensating scales. The number of individuals of each species was also recorded per pot. Total length down to the nearest centimetre, sex, and gonad maturity were recorded for all blue cod, and the sagittal otolith removed from a representative size range of males and females, from which the weight of each fish was recorded to the nearest 10 g. Otoliths were removed from a target of five fish of each sex per one centimetre size class over the available length range collected throughout the entire survey area.

All blue cod were sexed by dissection and direct examination of the gonads (Carbines 2004a). Gonads were also recorded as one of five stages as follows: 1, immature or resting; 2, maturing (oocytes visible in females); 3, mature (hyaline oocytes in females, milt expressible in males); 4, running ripe (eggs and milt free flowing); 5, spent (See Beentjes & Francis 2011).

2.6 Otolith preparation and reading

Due to the small size of blue cod otoliths, the most precise method for ageing is the thin section technique (Carbines 2004b). Collected otoliths were rinsed with water, air-dried, and stored in paper envelopes. These were later embedded in Araldite polymer resin, baked, and sectioned along the transverse plane with a diamond-tipped cut-off wheel. Sections were then coated with a slide mountant and sanded with 600-grit sandpaper to below 1 mm thickness before viewing. Sections were observed at ×40 and ×100 magnification under transmitted light with a compound microscope.

Otolith sections exhibit alternating opaque and translucent zones and age estimates are made by counting the number of annuli (opaque zones) from the core to the distal edge of the section, a technique previously validated and a protocol described for blue cod by Carbines (2004b). Translucent zones are used to define each complete opaque zone, i.e., annuli are counted only if they have a translucent zone on both sides. The readability of each otolith was also graded from 1 (excellent) to 5 (unreadable). Otoliths were read independently by two readers (G. Carbines and N. Usmar). Where counts differed, readers consulted to resolve the final age estimate. Otoliths given a grade 5 (unreadable) were removed from the analysis.

2.7 Data analysis

The data analyses follow the methods and equations described in the blue cod potting survey standards and specification document (Beentjes & Francis 2011).

CPUE for fish of minimum legal size

The potting survey manual does not provide equations for calculating catch rates of fish greater than the minimum legal size (MLS), however the approach that has been used in recent years is an extension of the equations for calculating catch rates for the entire catch. For blue cod potting surveys, individual fish weights are measured for only a subset of the sampled fish, and catch rates for fish greater than or equal to the MLS are based on the predicted weight of individual fish based on their length. The set-specific CPUE (kg.pot^{-1}) for fish greater than the MLS is,

$$C_{st}^{legal} = \left(\sum_{p} \sum_{k=1,2} \sum_{l \geq MLS} f_{lkpst} \, a_k \, l^{b_k} \right) \Big/ m \qquad (1)$$

where f_{lkpst} is the number of fish of length l and sex k (k=1 for males and k=2 for females) caught in pot p of set s of stratum t, m is the number of pot lifts in set s, and a_k and b_k are sex-specific length-weight parameters (described below). Note that the above equation assumes that all fish have been measured for length.

The sex-specific length-weight parameters a_k, b_k are calculated by fitting (maximum likelihood) the following equation to all samples where length, weight, and sex were recorded:

$$w_{ki} = a_k \left(l_{ki}\right)^{b_k} \varepsilon_{ki} \qquad (2)$$

where w_{ki} and l_{ki} are the weight and length of fish i of sex k and the ε_{ki} are normally distributed. The equations for calculating the stratum and survey catch rates and CVs for fish greater than or equal to the MLS follow those in the potting survey manual (equations 2–5 of Beentjes & Francis 2011), replacing $\bar{C}_{st}$ with C_{st}^{legal} .

Length frequency, age frequency and total mortality estimates
Calculation of survey-level length frequency (LFs), age frequency (AFs), and total mortality (Z) follow the equations described in the potting survey manual (Beentjes & Francis 2011). Uncertainty in the LFs, AFs and Z estimates were calculated using the bootstrap procedures described in the survey manual. The LF and AF CVs were based on 300 bootstrap replicates and the Z confidence limits were based on 1000 replicates.

Growth parameters
Von Bertalanffy growth models were fitted (maximum likelihood) to the sex-specific length-age data:

$$l_{ki} = L_k^{\infty}\left(1-\exp\left(K_k\left(t_{ki}-t_k^0\right)\right)\right)+\varepsilon_{ki} \qquad (3)$$

where l_{ki} and t_{ki} are the length (cm) and age of fish i of sex k, respectively, L_k^{∞}, K_k, and t_k^0 are parameters of the growth model for sex k, and the ε_{ki} are normally distributed.

The estimated growth parameters, L_k^{∞}, K_k, and t_k^0 , were used in the spawning biomass per recruit analyses.

Spawning biomass per recruit calculations
Spawning biomass per recruit (*SPR*, Ministry of Fisheries 2011) analysis estimates the impact of fishing on the reproductive capacity of the stock. *SPR* is a deterministic calculation, dependent on population growth, natural and fishing mortality, maturation, and fishing selectivity. For blue cod, the calculations are based on age- and sex-specific dynamics and spawning biomass is summed over male and female fish. The following equations give the number of fish at age a and sex k (N_{ka}) and the spawning biomass per recruit (S_F) for a given F:

$$N_{ka} = \begin{cases} 0.5 & a=0 \\ N_{k,a-1}\exp\left(-s_{k,a-1}F-M\right) & 1 \geq a < mage \\ N_{k,a-1}\exp\left(-s_{k,a-1}F-M\right) \Big/ 1-\exp\left(-s_{k,a-1}F-M\right) & a = mage \end{cases} \qquad (4)$$

$$S_F = \sum_k \sum_a \left(m_a a_k \left(l_{ka}\right)^{b_k} N_{ka} \right) \qquad (5)$$

where M is the natural mortality rate, s_{ka} is the selectivity for age a and sex k, m_a is the maturity for age a, l_{ka} is the mean length for age a and sex k, *mage* is the maximum age (50) and a_k and b_k are the length-weight parameters for sex k (see equation 2). $F_{\%SPR}$ is the fishing mortality (F) at a given spawning biomass per recruit (%SPR) relative to the spawning biomass per recruit in the absence of fishing $\left(\text{i.e. } S_f / S_0\right)$.

Population parameters are either estimated based on survey data (s_{ka} , l_{ka} , a_k and b_k) or fixed at default values as specified in the potting survey manual: the instantaneous natural mortality rate is assumed to be 0.14, with sensitivity analyses conducted for *M* values of 0.11 and 0.17; the maturation ogive assumes fish under age 3 are all immature, proportions mature of 0.1, 0.4, 0.7 for ages 4, 5, and 6, respectively, and 100% maturity for fish aged 7 and older; and fishery selectivity is assumed to be knife-edged at the age at MLS. The estimate of current fishing mortality (*F*) is equal to *Z-M*, and the SINS working group determined that the age of recruitment for the Z calculations would be the age where both male and female blue cod were at or above the MLS. Z and *SPR* results are also provided for ages at recruitment from 5 through to 10.

Note that the above equations assume that the surveys which generate the length-age data (and von Bertalanffy growth curves) occur at the time of spawning so that a fish aged 3 is exactly 3 years old. Also, knife-edged fishery selectivity is interpreted to mean that age-classes become fully selected when they reach the birthday where their mean length-at-age is greater than or equal to the MLS. Alternative interpretations of knife-edge selectivity are possible – for example, assuming full selectivity at the exact age where the mean length is equal to the MLS (i.e., full selectivity at some mid-point in the year).

2.8 Pot catches as a proxy for abundance and size structure

To determine how well catch from potting surveys performs as a proxy for relative abundance and size structure, we attempted to estimate blue cod abundance and population structure using remotely flown video transects immediately prior to potting at up to ten survey sites.

Sample collection
The drop under water video (DUV) system used consists of a 35 kg bulb keel and tail fins which steady and orient a forward and downward facing mounting platform, fitted with a low-light camera and scaling lasers (Morrison & Carbines 2006, Carbines & Cole 2009, Beentjes & Carbines 2012, Carbines & Beentjes 2012, Compton et al. 2012, Carbines & Haist 2014, 2017a, 2017b). It was suspended beneath the vessel by a rope and a live-feed video cable so that location, time, depth, and date were all burned in real time onto the recorded digital video footage integrated with a surface Geographical Positioning System (GPS) and depth sounder.

The video camera was deployed at a height of at least 1.5 m off the seabed and the vessel steamed through the sample area. Once the speed of the surface vessel exceeded that of the deployed video, the keel and tail fin orients the platform forward, and the video records a transect of approximately 600 m length. Contact with the seabed is avoided by raising and lowering the video from the surface vessel throughout each transect and scaling lasers are used to back-calculate the size and variations of transect width. Transects were carried out between 0700 and 1630 hours, when the swell was no more than a meter, and when drift speed exceeded 0.8 ms^{-1} (to prevent fish being able to follow the video and re-enter the video transect). At least five replicate video transects were done throughout at each site directly prior to sampling with six replicate pots (as described in Section 2.5).

Video analysis
Each video transect was processed (viewed) twice. On the first viewing, transect dimensions were geo-referenced and partitioned into general benthic habitat sections. All blue cod were geo-referenced and scaling lasers were used to estimate fish length (Morrison & Carbines 2006, Carbines & Usmar 2013). At the location of each blue cod, a benthic habitat sub-transect was sampled (approximately 5 m before and after the fish observed). During the second viewing, each section of general habitat was sampled with at least five sequential sub-transects to record transect width from scaling-lasers and provide fish independent descriptions of benthic habitat. Both fish-dependent and fish-independent habitat sub-

transects recorded primary (geological) substrata (categories of grain size from sand to bedrock) and secondary habitat structure (categories of overlaying organic or geological benthic habitat), percentage cover (e.g., shells, sponges, macro-algae, etc.) topographic complexity and actual counts of benthic species where possible.

Data analysis
Abundance estimates from DUV transects were examined in relation to catch so as to compare the catchability of survey pots. Where appropriate correlations were made between abundance and catch, proportional length frequencies were then compared between these methods to examine size selectivity (Cole et al. 2001, Morrison & Carbines 2006, Beentjes & Carbines 2012, Carbines & Beentjes 2012, Carbines & Haist 2014, 2017a, 2017b).

3 RESULTS

3.1 Sites surveyed

Forty random sites (6 pots per site, 240 pot lifts) were surveyed over nineteen fishable days from 5 April to 17 May 2013 (Table 1, Figure 1 and Appendix 2). The survey used 36 sites in phase 1 (6 per stratum) with 4 allocated to phase 2, depth ranged from 14 to 151 m (Table 1). Environmental data recorded throughout the 2013 south Otago survey are presented in Appendix 3 and are stored on the Ministry for Primary Industries database *trawl*. The ADCP data is archived in a spreadsheet with the Research Data Manager, NIWA, Greta Point, Wellington.

3.2 Catch

A total of 2454 kg of catch was taken during the 2013 south Otago random site potting survey, of which 1287 kg (98%) was blue cod, consisting of 2397 fish (Table 2). Bycatch included four fish species, one octopus species and one crab species (Table 2). The five most common bycatch species by weight were octopus (*Octopus cordiformis*), tarakihi (*Nemadactylus macropterus*), scarlet wrasse (*Pseudolabrus miles*), red cod (*Pseudophycis bachus*), and banded wrasse (*Notolabrus fucicola*) (Table 2).

The mean catch rates of blue cod (all sizes) ranged from 0.79 kg.pot^{-1} for the coastal Otago Peninsula stratum (1), to 13.65 kg.pot^{-1} in the southern 50–80 m depth stratum (6) off the Toko river mouth (Table 3, Figure 2). Overall mean catch rate and CV were 6.24 kg.pot^{-1} and 19.88%. For blue cod 30 cm and over (local minimum legal size) the highest catches also came from stratum 6 (12.8 kg.pot^{-1}) and the lowest catch rates were also from stratum 1 (0.70 kg.pot^{-1}). Overall mean catch rate and CV for legal sized fish were 5.06 kg.pot^{-1} and 23.0 (Table 4, Figure 2).

3.3 Biological and length frequency data

All of the 2397 blue cod caught during the 2013 south Otago random site survey were measured for length and sexed by dissection and visual examination of gonads (Figure 3).

Sex ratio
For all blue cod the sex ratio ranged from 1:0.1 (M:F) in the Otago Peninsula stratum (1) to 1:1.4 in the central 50–80 m depth stratum (5), and overall were 55% male (1:0.8) (Table 5). The sex ratio for blue cod 30 cm and over (local minimum legal size) ranged from 1:0.1 (M:F) in the inshore southern coastal stratum (2) to 1:1.1 (M:F) in the offshore stratum (3), and was overall 73% males (1:0.3) (Table 5). Sex ratios of legal size blue cod were also female dominated in the offshore stratum 3, but not in the inshore

stratum (5). The size of blue cod ranged from 12 to 50 cm for females and 16 to 55 cm for males (Table 5).

Length frequency
The length frequency distributions were often bimodal with a dominant mode of small fish (21–22 cm) among all inshore strata apart from the Otago Peninsula coast (Figure 3). Thirty-seven percent of inshore (5 strata) blue cod caught were of legal size and 72% of those in the offshore stratum were of legal size.

Biological data
Of the 2177 blue cod examined in the five inshore strata, 91.4% of the males and 96.7% of the females had early maturing gonads, and only 0.3% of males and 0.1% of females were either spawning or spent (Table 6). Of the 220 blue cod examined in the offshore stratum, 93.7% of the males and 46.4% of the females had early maturing gonads, but 4.3% of males and 45.6% of females were either spawning or spent (Table 7).

Otoliths and individual fish weights were taken from 305 blue cod selected across the available size range throughout the five inshore survey strata, and from 200 blue cod selected across the available size range throughout the offshore stratum. The survey wide length-weight relationship analysis included 240 females (range 12–48 cm) and 265 males (range 16–55 cm) from all strata. Using the derived model $W = aL^b$, the length-weight parameters for south Otago in 2013 were: males – a = 0.008472, b = 3.19011, females – a = 0.008617, b = 3.1863.

3.4 Ageing (between reader analyses)

From 334 otoliths collected from the five inshore strata during the 2013 south Otago survey, 29 were rejected as unreadable or damaged, leaving 305 otoliths (176 males 16–55 cm, 129 females 13–48 cm (Table 8)). These otoliths were collected across all inshore strata (Appendix 5). Initial independently derived reader estimates of otolith age class are compared in Figure 4 and show 58% agreement between the two readers, with reader 2 generally estimating slightly lower age classes than reader 1 (tabulated in Appendix 5). When the differences between age class estimates were resolved by agreement between the readers, reader 1 was 66% consistent with the agreed age class and reader 2 was 84% consistent with the agreed age classes (Figure 4, Appendix 6).

From 201 otoliths collected from the offshore stratum (3) during the 2013 south Otago survey, only one was rejected as unreadable or damaged, leaving 200 otoliths (89 males 17–53 cm, 111 females 12–47 cm (Table 9)). Initial independently derived reader estimates of otolith age class are compared in Figure 5 and show 39% agreement between the two readers, with reader 2 again estimating slightly lower age classes than reader 1 (tabulated in Appendix 7). When the differences between age class estimates were resolved by agreement between the readers, reader 1 was 85% consistent with the agreed age class and reader 2 was 60% consistent with the agreed age classes (Figure 5, Appendix 8).

3.5 Growth

The cumulative distribution for length and age of blue cod from the 2013 south Otago inshore strata and offshore stratum are shown in Figure 6. The fitted von Bertalanffy growth models for the five inshore strata are shown in Figure 7, and the growth parameters (K, t_0 and L_{inf}) shown below.

Inshore Parameter	Males	Females
K	0.0908	0.0922
T_0	-1.5703	-1.8841
L_{inf}	56.8	50.1

The fitted von Bertalanffy growth models for the 2013 offshore stratum (3) are shown in Figure 8, and the growth parameters (K, t_0 *and* L_{inf}) shown below.

Offshore Parameter	Males	Females
K	0.1305	0.1208
T_0	-0.8439	-1.2442
L_{inf}	51.7	47.1

The fitted von Bertalanffy growth models for the 2013 total survey area are shown in Figure 9, and the growth parameters (K, t_0 *and* L_{inf}) shown below.

All strata Parameter	Males	Females
K	0.1034	0.1085
T_0	-1.2828	-1.4339
L_{inf}	54.8	48.2

A comparison of inshore and offshore male and female von Bertalanffy growth curves is given in Figure 10.

3.6 Length and age composition

The scaled length and age distributions for the five inshore strata are shown for males and females in Figure 11. Length frequency distributions were bimodal, with a very dominant mode centred at about 21–22 cm for both males and females. Males were larger than females by an average of 6.8 cm (Figure 11). Among the five inshore strata age ranged from 2 to 32 years (Table 8), but with very few fish older than 15 years (Figure 11). For both males and females the dominant age-class was 4 years (Figure 11). The mean weighted coefficients of variation (MWCVs) around the inshore strata age distributions are moderate (about 30%) indicating that fish sampled in the 2013 inshore strata provide a fair representation of the overall population. The inshore age-length-keys (ALKs) by sex are shown in Appendices 9 and 10, mean-age-at-length is shown in Appendix 13.

The scaled length and age distributions for the offshore stratum are shown for males and females in Figure 12. Length frequency distributions were also bimodal, but the dominant length mode was centred at about 40 cm for males and 33 cm for females. Males were larger than females by an average of 5.8 cm (Figure 12). Offshore, age ranged from 1 to 29 years (Table 9), but with more fish older than 15 years compared to the inshore strata (Figure 12). For males the dominant age-class was 10 years, but for females it was three years (Figure 12). However, the mean weighted coefficients of variation (MWCVs) around the offshore survey age distributions were very high (over 60%) indicating that fish sampled in the 2013 offshore stratum provide a poor representation of the overall population. The offshore age-length-keys (ALKs) by sex are shown in Appendices 11 and 12, mean-age-at-length is shown in Appendix 14. The scaled length and age distributions for all strata are also shown for males and females in Figure 13.

3.7 Total mortality (Z) estimates

Total mortality estimates (Z) for the 2013 south Otago potting survey was calculated using the Chapman-Robson estimator with 95% confidence intervals for these estimates based on a bootstrap procedure. For the five inshore strata, estimates of Z increase with the assumed age-at-recruitment to the fishery from 0.18 at 5 years to 0.25 at 10 years (Table 10). For the offshore stratum, *Z* also increases with the assumed age-at-recruitment to the fishery from 0.13 at 5 years to 0.21 at 10 years (Table 11). For all strata, the estimates of *Z* increase from 0.17 at 5 years to 0.24 at 10 years (Table 12).

3.8 Spawner per recruit analyses

The age- and sex-specific values for fish size, maturity, and selectivity used in the SPR analysis are given in Appendix 15 for inshore strata and Appendix 16 for offshore strata.

Spawning biomass per recruit analyses is plotted as %SPR versus fishing mortality rate for the five inshore strata (Figure 14), the offshore stratum (Figure 15), and all strata (Figure 16). Mortality parameters used in the analyses, and resulting %SPR values are shown in Tables 13–15. For the inshore strata (based on the default value of *M* of 0.14 and a fully-selected age of 9 years), the fishing mortality estimate was 0.22, corresponding to a spawner biomass per recruit ratio of 57% at M=0.14. This indicates that at recent levels of fishing mortality, the expected contribution to the spawning biomass over the lifetime of an average inshore strata recruit has been reduced to about 57% of the contribution in the absence of fishing. Inshore $F_{\%SPR}$ estimates for *M* values of 0.11 and 0.17 ranged from 42% to 73% (Table 13).

For the offshore stratum (based on the default value of *M* of 0.14 and a fully-selected age of 8 years), the fishing mortality estimate was 0.18, corresponding to a spawner biomass per recruit ratio of 74% at M=0.14. This indicates that at recent levels of fishing mortality, the expected contribution to the spawning biomass over the lifetime of an average offshore stratum recruit has been reduced to about 74% of the contribution in the absence of fishing. Offshore $F_{\%SPR}$ estimates for *M* values of 0.11 and 0.17 ranged from 54% to 95% (Table 13).

3.9 Pot catches as a proxy for abundance and size structure

Video counts versus pot catches
Due to sea conditions (i.e., swells over 1.0 m and/or poor bottom water visibility), only five sites were able to be surveyed with flown video transects prior to potting in the 2013 south Otago survey. The 2013 north Otago potting survey encountered similar environmental difficulties (Carbines & Haist 2018), and was able to video survey only one site prior to potting (Figure 17). To further investigate the relationship between potting survey catch rates and size structure with direct *in situ* video observations of blue cod in the general Otago region, the 2013 north Otago site was pooled with the five 2013 south Otago potting survey sites (Table 16).

A total of 28 drop underwater video (DUV) transects (4–5 per site) were undertaken at five south Otago and one north Otago random potting survey sites (36 pot lifts) directly prior to sampling with type 2 survey pots (Table 16). The DUV surveyed over 18 km of transects with an average transect width of 2.7 m (s.e. ± 0.1 m) covering a total area of 46 100 m^2. A total of 2777 blue cod were observed using DUV, while the survey pots caught 478 blue cod (Table 16).

Species caught and observed
A total catch of 483 individuals was taken by pots at concurrent DUV surveyed sites, 99% of which were blue cod (Table 17). At the DUV surveyed sites, bycatch from potting included two fish and one crab species. Total potting bycatch included two tarakihi (*Nemadactylusma cropterus*), two paddle crabs (*Ovalipes catharus)* and one leatherjacket (*Parika scaber*).

A total of 3143 individuals were observed in DUV transects, 88% of which were blue cod (Table 18). Fourteen fish species, one crab and one squid species were observed in DUV transects, the five most common of which were tarakihi, sea perch (*Helicolenus* spp.), paddle crabs, southern bastard cod (*Pseudophycis barbata*), and girdled wrasse (*Notolabrus cinctus*).

Length frequency comparisons

Fish observed either off the bottom or at a camera angle over 45 degrees were removed (n=173) to improve precision (See Carbines & Usmar 2013), and the resulting proportional length frequency distribution showed that the DUV sampled a considerably greater proportion of blue cod below 20 cm than was caught by pots (Figure 18). Pots also caught proportionally more blue cod over 20 cm, and the cumulative distribution plots of length frequency confirms that the video observations had a much higher proportion of smaller fish than pots (Figure 18).

Comparison of catch rates and counts

Fish densities estimated by the area-swept DUV method for three size classes of blue cod are shown in Figure 19. Seventy percent of all blue cod observed by the DUV were at site 5R2 which recorded an average total density of 21.2 blue cod per 100 m^2 (s.e. ± 5.3). Site 5R2 had very high densities of fish below 30 cm and site 5R4 had relatively high densities of legal size blue cod. Subsequently these sites had the highest catch rates of fish below and above 30 cm respectively (Figure 19). However, the proportional differential between what was observed and then caught increased with each size class (Figure 19). Relatively low densities of fish observed at the north Otago site (1R1) site also preceded relatively high catches (Figure 19).

Pots caught few fish below 20 cm (Figure 19), but the correlation between the average site density and catch rate was 0.85 (Figure 20). For fish 20–29 cm and of legal size the correlations between the average site density and catch rate were 0.88 and 0.89 respectively (Figure 20). All correlations were strongly influenced by the relatively high counts and catch at sites 5R2 and 5R4 (Figure 20).

Benthic habitat descriptions and utilisation

Within the area swept by the DUV, 147 general habitat breaks were identified and 735 fish-independent habitat transects were recorded within them (Table 16). A total of 2777 blue cod were observed with associated habitat using DUV (Table 16). Benthic habitat data from the DUV method are presented in Figures 21 and 22, and a ratio of fish-dependent and fish-independent habitat observations was used to determine which primary substrata and secondary habitat structures blue cod are disproportionately more associated with.

In total, seven types of primary substrate were observed, and the fish-independent habitat observations show the main primary substrates were bedrock/sand, sand/shell/gravel, and sand (Figure 21). The smallest blue cod (less than 20 cm) were observed mostly with shell grit/gravel, 20–29 cm blue cod were observed mostly with bedrock/sand, and legal size blue cod were observed mostly with sand/shell grit (Figure 21).

The main primary substrates observed in fish-dependent habitat observations were bedrock/sand, but the ratio of the substrate category proportions observed between fish-dependent versus fish-independent habitat observations (i.e., substrate category occupancy in proportion to its availability), showed that smaller blue cod were disproportionately associated with shell grit/gravel, while larger blue cod were disproportionately associated with sand/shell grit and gravel (Figure 21).

In total thirteen types of secondary habitat structures were observed, and the fish-independent habitat observations show that the main secondary habitat structures observed were horse mussels (Figure 22). Blue cod of all size classes were also observed frequently with horse mussels and various forms of sponge (Figure 22). The ratio of fish-dependent and fish-independent secondary habitat categories confirms that larger blue cod were disproportionately associated with horse mussels and various forms of sponge, while smaller blue cod were disproportionately associated with sponge/horse mussel, sponges, and bryozoans (Figure 22).

4 DISCUSSION

4.1 Survey time series

The 2013 blue cod potting survey was the second random site survey done in south Otago, but the first to include all six strata (Figure 1). The overall catch rates of all blue cod (Table 3) and legal sized blue cod (at least 30 cm, Table 4) increased 42% and 76% respectively since those recorded in the initial 2010 random site potting survey for strata 1, 3, and 6 (See Figure 2). In 2013, there was an increase in catch rates in both strata 3 and 6 for all blue cod and legal sized blue cod, while catches in stratum 1 remained relatively stable (Figure 2). The overall CV for the 2013 survey catch rates was 19.9% for all blue cod and 23.0% for legal sized blue cod (Tables 3 and 4) and were marginally higher than the overall CVs from the previous 2010 survey (Beentjes & Carbines 2011).

4.2 Reproductive condition

Observations of gonad stages from inshore strata in 2013 were mainly in the early maturing stage, but with some running ripe and spent gonads (Table 6). This indicates that the timing of the survey (autumn) followed the conclusion of the spawning season and was consistent with the previous survey (Beentjes & Carbines 2011). Observations of gonad stages in the offshore stratum in 2013 were also mainly in the early maturing stage for males, but 46% of females had spent gonads (Table 7). This indicates that blue cod in the offshore area had more recently concluded the spawning season than in the inshore strata, and was not consistent with the previous survey (Beentjes & Carbines 2011).

Observation of running ripe and spent gonads at this time of year suggest a longer spawning period than previously thought (Carbines 2004a). Furthermore, differences between the inshore strata and the offshore stratum show both temporal and spatial variability in the spawning period of south Otago blue cod. As the 2013 potting survey was undertaken outside the main spawning period it was not possible to determine size or age-at-maturity.

4.3 Size and sex ratio

The balanced overall sex ratio for all blue cod (1:0.8 M:F, 56% male) was not consistent among strata (Table 5). The Otago Peninsula stratum (1) was heavily male dominated (1:0.1 M:F, 88% male), while the inshore stratum 5 (1:1.4 M:F, 42% male) and the offshore stratum 3 (1:1.3 M:F, 43% male) were female dominated for all size blue cod (Table 5). For legal size blue cod (at least 30 cm) only the offshore stratum was female dominated (Table 5).

Blue cod are protogynous hermaphrodites with some (but not all) females changing into males as they grow (Carbines 2004a). The finding that males were larger on average than females and that the largest fish were males (Table 5) is consistent with the sex structure in a protogynous hermaphrodite. However, the male skewed sex ratios of legal sized blue cod in the most accessible strata are contrary to an expected dominance of females resulting from selective fishing (MLS) removing the larger terminal sex males. Carbines (2004a) hypothesised that the shift towards a higher proportion of males in heavily fished blue cod populations may be caused by removal of the inhibitory aggressive behavioural effects of large males resulting in a higher rate (and possibly earlier onset) of sex change by the remaining primary females (e.g., Kobayashi et al. 1993a, 1993b). This hypothesis is supported by the predominance of males in the inshore strata most accessible to fishing.

4.4 Population length and age structure

Length frequency distributions (Figure 3) were quite different between the deep-water offshore stratum (72% legal size) and the inshore strata (37% legal size). Offshore blue cod were mainly over 30 cm and there were few fish below 20 cm (Figure 12), while inshore blue cod were mainly below 25 cm (Figure 11). The average size of offshore blue cod was 6.5 cm and 8.0 cm larger for male and females, respectively, than for inshore blue cod (Table 5). Inshore, there was a very large number of blue cod between 18 cm and 24 cm (Figure 11), caught mainly in strata 2, 4 and 5 off the Taieri and Dunedin coasts (Figure 1). Note that these three strata were not surveyed in the 2010 survey (Beentjes & Carbines 2011).

In 2010 only strata 1, 3, and 6 were surveyed (Beentjes & Carbines 2011). When only these strata are compared in 2013, the average size has increased by 5.8 cm for males and 4.6 cm for females since the 2010 survey (Beentjes & Carbines 2011). Average size increased within all strata, but most dramatically in the offshore stratum (by 9.9 cm for males and 7.2 cm for females), while the proportion of legal sized blue cod caught in the three comparable strata of the 2013 south Otago survey (49%) rose by 28% since the 2010 survey (21% in Beentjes & Carbines 2011).

The age distributions, and total mortality estimates are based on scaled length data that were weighted (scaled) by stratum area. Scaling by area assumes that the size of each stratum is directly proportional to the amount of blue cod habitat, (i.e., area is assumed to be a proxy for habitat), though this seems unlikely for blue cod habitat in some areas (Carbines & Cole 2009, Carbines & Haist 2012, 2017a, 2017b). With improving seabed habitat mapping, in future it may be possible to scale catch data to more detailed estimates of the actual areas of suitable blue cod habitat (Figures 21 and 22) within each stratum – as was recommended by the expert review panel following a workshop on blue cod potting surveys in April 2009 (Stephenson et al. 2009). However, as area is currently the only available proxy for blue cod habitat it was used for scaling.

The overall scaled length frequency distribution for the 2013 south Otago survey (Figure 13) shows a dominant size class from 18 cm to 24 cm among inshore strata 2, 4 and 5 (Figure 3). The resulting population age structure has a steep decline from four to five years, but age classes are relatively stable out to 11 years, with a low proportion of fish older than 15 years. In contrast, the 2010 south Otago survey (strata 1, 3, and 6 only) had very few blue cod less than 20 cm and reasonably similar strata length frequency distributions (Carbines & Beentjes 2012).

4.5 Total mortality (*Z*)

Although mortality estimates (*Z*) from the 2010 south Otago survey (0.25–0.27, age at recruitment 5–8 years, Beentjes & Carbines 2011) were not derived from all strata (i.e., 1, 3, and 6 only), they were higher than estimates from either inshore strata (0.18–0.21, age at recruitment 5–8 years, Table 10) or the offshore stratum (0.13–0.18, age at recruitment 5–8 years, Table 11) of the 2013 north Otago survey.

4.6 Stock status (spawning biomass per recruit ratio analyses)

The Ministry of Fisheries *Harvest Strategy Standard* (Ministry of Fisheries 2011) specifies that a Fishery Plan should include a fishery target reference point, and this may be expressed in terms of biomass or fishing mortality. The more appropriate target reference point for blue cod is F_{MSY}, which is the amount of fishing mortality that results in the maximum sustainable yield. The recommended proxy for F_{MSY} is the level of spawner per recruit $F_{\%SPR}$. The 'Operational Guidelines for New Zealand's Harvest Strategy Standard' (Ministry of Fisheries 2011) includes the following table of recommended default values for F_{MSY} (expressed as $F_{\%SPR}$ levels from spawning biomass per recruit analysis), and also for B_{MSY} (expressed as $\%B_0$).

Productivity level	$\%B_0$	$F_{\%SPR}$
High productivity	25%	$F_{30\%}$
Medium productivity	35%	$F_{40\%}$
Low productivity	40%	$F_{45\%}$
Very low productivity	≥ 45%	≤ $F_{50\%}$

Based on the 'Operational Guidelines for New Zealand's Harvest Strategy Standard' (Ministry of Fisheries 2011) and recommendations from the Southern Inshore Working Group, blue cod is categorised as an exploited species with low productivity (on account of complications related to sex change) and hence the recommended default proxy for F_{MSY} is $F_{45\%}$. Our SPR estimates for the default M value of 0.14 were $F_{57\%}$ for inshore strata, and $F_{74\%}$ for the offshore stratum of the 2013 south Otago survey (Tables 13 and 14), indicating that the expected contribution to the spawning biomass over the lifetime of an average inshore and offshore recruit has been reduced to 57% and 74% respectively of the contribution in the absence of fishing. This is a relatively low level of exploitation (F) compared to other potting survey area estimates (Ministry for Primary Industries 2017) and the F_{MSY} target reference points are well within the Ministry of Fisheries specified target.

Sensitivity analyses using M values of 0.11 and 0.17 (20% below and above the default of 0.14) resulted in substantial differences in the $F_{\%SPR}$ from the default M value (Tables 13 and 14, see Figures 14 and 15). A higher natural mortality (0.17) increased spawning biomass contribution to 73% inshore and 95% offshore. Conversely, lower mortality (0.11) decreased the spawning biomass contribution by similar amounts.

4.7 Does potting provide a robust index of abundance and size structure?

Fishing gear, bait type and soak time are standardised in blue cod potting surveys (see Beentjes & Francis 2011), but other factors such as fish behaviour and environmental features can influence catchability and size selectivity in passive capture methods such as potting (Furevik 1994, Fogarty & Addison 1997, Robichaud et al. 2000). Cole et al. (2001) found that blue cod catch rates were unrelated to both time and tide in the Marlborough Sounds. However, when compared to diver transects, pots tended to under-sample small blue cod, being selective for fish over 15 cm (Cole et al. 2001). While there was a positive relationship between blue cod catch from pots (Pot Plan 1 from Beentjes & Francis 2011) and diver transects, it was weak and much of the variation remained unexplained (Cole et al. 2001).

During the 2010 Marlborough Sounds potting survey concurrent observations of blue cod abundance from a flown dropped underwater video (DUV) was also used at 20 survey sites to investigate the relationship between observed density and sizes of blue cod and subsequent catch in nine type 1 pots (pot plan 1 in Beentjes & Francis 2011). The DUV had a much higher proportion of small blue cod than the type 1 pots, and a correlation between average density and catch was 0.27 for all and -0.19 for blue cod 30 cm or more (Beentjes & Carbines 2012). During the 2010 Foveaux Strait potting survey concurrent observations of blue cod abundance from a DUV were also obtained from 17 sites with type 2 pots (pot plan 2 in Beentjes & Francis 2011). The DUV again had a higher proportion of small blue cod than the type 2 pots, and a correlation between average density and catch was only 0.50 for all and 0.54 for blue cod 20 cm or more (Carbines & Beentjes 2012). In the current study, the DUV also sampled a much greater proportion of blue cod below 20 cm (Figure 18). However, the correlations between blue cod density observed by video and the subsequent catch rates in type 2 survey pots in the current study were considerably stronger for all size classes of blue cod (Figure 20) than those observed in similar studies of both type 1 pots (Beentjes and Carbines 2012) and type 2 pots (Carbines and Beentjes 2012, Carbines & Haist 2014, 2017a, 2017b).

Continuous video recordings of blue cod entries and exits from pots also show that less than 8% of approaches lead to entries, and that local topography can constrain pot entries in some situations (Cole et al. 2004). Environmental conditions that maximise catchability strengthen the relationship between what is observed in situ and what is subsequently caught, and during the current study, sites seem to have been more homogenous in benthic habitat, with few fish independent observations of no structure (Figure 22). After several comparisons it has become clear that previous studies with weaker catchability had observed mostly "no structure" among fish independent observations (Beentjes & Carbines 2012, Carbines & Beentjes 2012, Carbines & Haist 2014, 2017a, 2017b), and the stronger relationship between catch and count observed in the current study may be due to a more homogenous benthic environment among the sites able be to surveyed with flown video transects (n=6) in the Otago surveys.

Pots have both size selectivity issues and high spatial variability in catchability of blue cod (Cole et al 2001, Beentjes & Carbines 2012, Carbines & Beentjes 2012, Carbines & Haist 2014, 2017a, 2017b). Consequently, catch rates and mortality estimates should probably not be compared between survey areas.

4.8 The importance of benthic habitat structure

By using the ratio of fish-dependent and fish-independent habitat observations it was possible to determine which primary substrate and secondary habitat categories blue cod were found in association with at a higher rate, than observed randomly in the benthic environment. Blue cod were most often found on shell grit/gravel, sand/shell grit/gravel and sand/shell grit (Figure 21) with horse mussels and/or sponge (Figure 22). Unlike most other areas DUV surveyed, there were relatively few areas devoid of secondary structure observed in south Otago and the "preferred" blue cod habitats of horse mussels and/or various forms of sponge were also the most common habitats observed in the benthic environment (Figure 22). This relative abundance of "preferred" blue cod habitat in the Otago DUV survey sites appears to be particularly important to small blue cod (Figure 22), and is likely the driver of some of the highest abundance estimates of blue cod ever recorded (Cole et al 2001, Beentjes & Carbines 2012, Carbines & Beentjes 2012, Carbines & Haist 2014, 2017a, 2017b).

Data on fish abundance and habitat from video provide information regarding environmental variables that appear to affect blue cod density and size structure. It identifies benthic habitats and structures of particular importance and allows for the construction of habitat maps, which will be particularly useful in terms of stratifying future potting surveys for more accurate scaling of relative abundance estimates (Stephenson et al. 2009). Video habitat data also provides a unique understanding of the ontogenetic needs of fish and can provide habitat information for other management purposes.

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Table 1: South Otago 2013 survey stratum area, number of phase 1 and 2 sites, pot lifts, and depth of sites.

	Size of strata *	Number of Selected sites (0)		Number of pot lifts (0)	Depth (m)	
Stratum	Area (km^2)	Phase 1	Phase 2	Total	Mean	Range
1	154.9	6	2	42	28.3	14–41
2	245.4	6	2	42	24.7	16–32
3	177.9	6		36	121.3	104–151
4	426.2	6		36	54.2	40–60
5	196.6	6		36	60.0	45–69
6	251.3	6		36	58.6	29–72
Total	1452.3	36	4	240	54.7	14–151

Table 2: Catch weights, numbers of blue cod, bycatch species, and percentage of total weight from the 2013 south Otago random sites (n=40) survey.

Common name	Scientific name	Catch (kg)	Number	Percent of total catch
Blue cod	*Parapercis colias*	1287	2397	98.13
Octopus	*Octopus cordiformis*	14.1	3	1.08
Tarakihi	*Nemadactylus macropterus*	6.2	40	0.47
Scarlet wrasse	*Pseudolabrus miles*	1.8	5	0.14
Red cod	*Pseudophycis bachus*	1.6	6	0.12
Banded wrasse	*Notolabrus fucicola*	0.5	1	0.04
Paddle crab	*Ovalipes catharus*	0.3	2	0.02
Total		1311.5	2454	100.00

Table 3: Mean catch rates for all blue cod caught in all strata of the 2013 south Otago random site survey, with the inshore strata and the offshore stratum presented separately. Catch rates are expressed as kg.pot^{-1} and s.e. and CV are set-based estimates. s.e., standard error, CV coefficient of variation.

Stratum	Sites	Pot lifts (N)	Mean (kg/pot)	s.e.	CV (%)
1	8	48	0.79	0.79	100.00
2	8	48	1.35	0.99	73.33
3	6	36	5.37	2.84	52.88
4	6	36	6.51	2.64	40.59
5	6	36	7.37	2.24	30.40
6	6	36	13.65	4.80	35.15
Total	40	240	6.24	1.24	19.88
Inshore Strata	34	204	6.36	1.36	21.33
Offshore Stratum	6	36	5.37	2.84	52.88

Table 4: Mean catch rates for blue cod 30 cm and over (MLS in BCO 3) caught in all strata of the 2013 south Otago random site survey, with the inshore strata and the offshore stratum presented separately. Catch rates are expressed as kg.pot^{-1} and s.e. and CV are set-based estimates. s.e., standard error, CV coefficient of variation.

Stratum	Sites	Pot lifts (N)	Mean (kg/pot)	s.e.	CV (%)
1	8	48	0.70	0.70	100.00
2	8	48	0.98	0.82	83.65
3	6	36	4.95	2.82	57.03
4	6	36	5.07	2.32	45.79
5	6	36	3.78	2.13	56.32
6	6	36	12.82	4.72	36.85
Total	40	240	5.06	1.17	23.03
Inshore Strata	34	204	5.08	1.27	24.98
Offshore Stratum	6	36	4.95	2.82	57.03

Table 5: Mean lengths of blue cod in the 2013 south Otago random site survey, by strata and sex: m, males; f, female. The sex ratio is shown as the number of females per male, and the percent of males (shown in brackets) is also given for all blue cod and those over the MLS (30 cm). The overall calculation is also done for inshore sites only (i.e., excluding the offshore stratum 3).

			Length (cm)			Sex ratio M:F (% male)	
Strata	Sex	N	Mean	Minimum	Maximum	All blue cod	≥ 30 cm
1	M	49	33.8	23	44	1:0.1(87.5)	1:0.2(86.8)
	F	7	29.0	22	32		
2	M	90	31.0	20	44	1:0.5(65.7)	1:0.1(92.0)
	F	47	23.8	15	41		
3	M	95	37.9	17	53	1:1.3(43.2)	1:1.1(48.8)
	F	125	32.1	12	47		
4	M	296	30.6	18	55	1:0.5(66.7)	1:0.3(75.0)
	F	148	27.3	18	48		
5	M	421	26.1	17	51	1:1.4(41.5)	1:0.4(70.9)
	F	593	21.4	13	44		
6	M	366	38.0	16	54	1:0.4(69.6)	1:0.3(77.9)
	F	160	30.8	13	50		
Overall (un-weighted)	M	1317	31.9	16	55	1:0.8(54.9)	1:0.4(72.6)
	F	1080	25.0	12	50		
Overall (un-weighted)	M	1222	31.4	16	55	1:0.8(56.1)	1:0.3(77.3)
Inshore Strata only	F	955	24.1	13	50		

Table 6: Gonad stages of south Otago blue cod in the 2013 random site survey inshore strata (i.e., excluding stratum 3). 1, immature or resting; 2, maturing (oocytes visible in females); 3, mature (hyaline oocytes in females, milt expressible in males); 4, running ripe (eggs and milt free flowing); 5, spent.

Inshore	Gonad stage (%)					
	1	2	3	4	5	N
Males	8.3	91.4	0.0	0.1	0.2	1222
Females	3.2	96.6	0.0	0.0	0.1	955

Table 7: Gonad stages of south Otago blue cod in the 2013 random site survey offshore stratum (3). 1, immature or resting; 2, maturing (oocytes visible in females); 3, mature (hyaline oocytes in females, milt expressible in males); 4, running ripe (eggs and milt free flowing); 5, spent.

Offshore	Gonad stage (%)					
	1	2	3	4	5	N
Males	1.1	93.7	1.1	1.1	3.2	95
Females	5.6	46.4	2.4	0.0	45.6	125

Table 8: Otolith raw data used in the catch at age, *Z* estimates, and SPR analyses for 2013 south Otago inshore random sites (i.e., all strata excluding stratum 3).

	No.	Length of aged fish (cm)			Age (years)		
Survey	otoliths	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Total	305	32.0	13	55	9.7	2	32
Male	176	35.1	16	55	10.7	2	32
Female	129	27.9	13	48	8.2	2	25

Table 9: Otolith raw data used in the catch at age, *Z* estimates, and SPR analyses for the 2013 south Otago offshore random sites (i.e., stratum 3 only).

	No.	Length of aged fish (cm)			Age (years)		
Survey	otoliths	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Total	200	34.5	12	53	10.4	1	29
Male	89	37.7	17	53	10.2	3	29
Female	111	31.8	12	47	9.8	1	28

Table 10: Blue cod total mortality estimates (*Z*) with 95% confidence intervals and corresponding spawning biomass per recruit ratios (assuming M=0.14) for ages of recruitment (AgeR) from 5 to 10 for the 2013 south Otago random site survey inshore strata (i.e., excluding stratum 3).

	Chapman-Robson Z			
		Confidence intervals		
AgeR	*Z*	Lower	Upper	%SPR
5	0.18	0.14	0.25	72.84
6	0.19	0.14	0.26	70.18
7	0.20	0.15	0.27	64.28
8	0.21	0.15	0.28	61.76
9	0.22	0.16	0.31	57.34
10	0.25	0.18	0.35	48.82

Table 11: Blue cod total mortality estimates (*Z*) with 95% confidence intervals and corresponding spawning biomass per recruit ratios (assuming M=0.14) for ages of recruitment (AgeR) from 5 to 10 for the 2013 south Otago random site survey offshore strata (i.e., stratum 3 only).

	Chapman-Robson Z			
		Confidence intervals		
AgeR	*Z*	Lower	Upper	%SPR
5	0.13	0.10	0.18	113.22
6	0.14	0.11	0.20	97.46
7	0.16	0.12	0.23	83.48
8	0.18	0.13	0.25	74.23
9	0.19	0.14	0.26	69.60
10	0.21	0.15	0.30	61.80

Table 12: Blue cod total mortality estimates (*Z*) with 95% confidence intervals and corresponding spawning biomass per recruit ratios (assuming M=0.14) for ages of recruitment (AgeR) from 5 to 10 for the 2013 south Otago random site survey all strata.

	Chapman-Robson Z			
		Confidence intervals		
AgeR	*Z*	Lower	Upper	%SPR
5	0.17	0.13	0.24	76.78
6	0.18	0.14	0.25	70.94
7	0.20	0.15	0.27	63.62
8	0.21	0.16	0.28	60.97
9	0.21	0.16	0.29	60.11
10	0.24	0.18	0.33	52.08

Table 13: Mortality rates and spawning biomass per recruit ratios, assuming an age of recruitment of 9, at three values of M (natural mortality) for the 2013 south Otago random site survey inshore strata (i.e., all strata except stratum 3). Z=total mortality.

M	Z	%SPR
0.11	0.22	42%
0.14	0.22	57%
0.17	0.22	73%

Table 14: Mortality rates and spawning biomass per recruit ratios, assuming an age of recruitment of 8, at three values of M (natural mortality) for the 2013 south Otago random site survey offshore stratum (i.e., stratum 3 only). Z=total mortality.

M	Z	%SPR
0.11	0.18	54%
0.14	0.18	74%
0.17	0.18	95%

Table 15: Mortality rates and spawning biomass per recruit ratios, assuming an age of recruitment of 8, at three values of M (natural mortality) for the 2013 south Otago random site survey all strata. Z=total mortality.

M	Z	%SPR
0.11	0.21	45%
0.14	0.21	61%
0.17	0.21	78%

Table 16: Drop underwater video (DUV) and pot sample details from random sites of the north and south Otago surveys. Stations are transects and pots. *=equivalent number of fish-dependent habitat quadrats.

	North Otago Survey		South Otago Survey	
	DUV	Pots	DUV	Pots
Sites	1	1	5	5
Stations	5	6	23	30
Habitat sections	25	-	122	-
Habitat quadrats	125	-	610	-
Total transects length	2 720 m	-	15 608 m	-
Mean transect length	544 m (± 65.7)	-	679 m (± 34.0)	-
Mean transect width	2.3 m (± 0.1)	-	2.7 m (± 0.1)	-
Total area swept	5 979 m^2	-	40 121 m^2	-
Blue cod number	133*	98	2644*	380
Blue cod length range (cm)	10–39	18–44	5–50	15–54
Blue cod mean length ± se	21.2±0.5	28.3±0.6	18.3±0.1	29.2±0.5

Table 17: Pot catch, numbers of blue cod, bycatch species, and percentage of total numbers from the 6 potted video sites from the north (TRI1301) and south (TRI1302) Otago potting surveys.

Common name	Scientific name	North Site (1)	South Sites (5)	Total Number	Percent catch
Blue cod	*Parapercis colias*	98	380	478	99.0
Tarakihi	*Nemadactylusma cropterus*		2	2	<0.1
Paddle crab	*Ovalipes catharus*		2	2	<0.1
Leatherjacket	*Parika scaber*	1		1	<0.1
Total		99	384	483	100.0

Table 18: Drop underwater video observed numbers of blue cod, bycatch species, and percentage of total numbers from 6 potted video sites from the north (TRI1301) and south (TRI1302) Otago potting surveys.

Common name	Scientific name	North Site (1)	South Sites (5)	Total Number	Percent of total catch
Blue cod	*Parapercis colias*	133	2644	2777	88.4
Tarakihi	*Nemadactylusma cropterus*	178	11	189	6.0
Sea perch	*Helicolenus* spp.		64	64	2.0
Paddle crab	*Ovalipes catharus*		27	27	0.9
Southern bastard cod	*Pseudophycis barbata*		14	14	0.4
Girdled wrasse	*Notolabrus cinctus*	1	12	13	0.4
Scarlet wrasse	*Pseudolabrus miles*	13		13	0.4
Skate	*Raja* spp.	2	7	9	0.3
Banded wrasse	*Notolabrus fucicola*		8	8	0.3
Spotty	*Notolabrus celidotus*	7		7	0.2
Flat fish	*Rhombosolea* spp.		6	6	0.2
Blue moki	*Latridopsis ciliaris*	2	4	6	0.2
Pig fish	*Congiopodus leucopaecilus*		4	4	0.1
Red cod	*Pseudophycis bachus*	8	3	3	0.1
Bigeye	*Pempheris adspersa*.		1	1	<0.1
Carpet shark	*Cephaloscyllium isabellum*	1		1	<0.1
Squid	*Nototodarus* spp		1	1	<0.1
Unidentified		*1*			<0.1
Total*		346	2806	3143	100

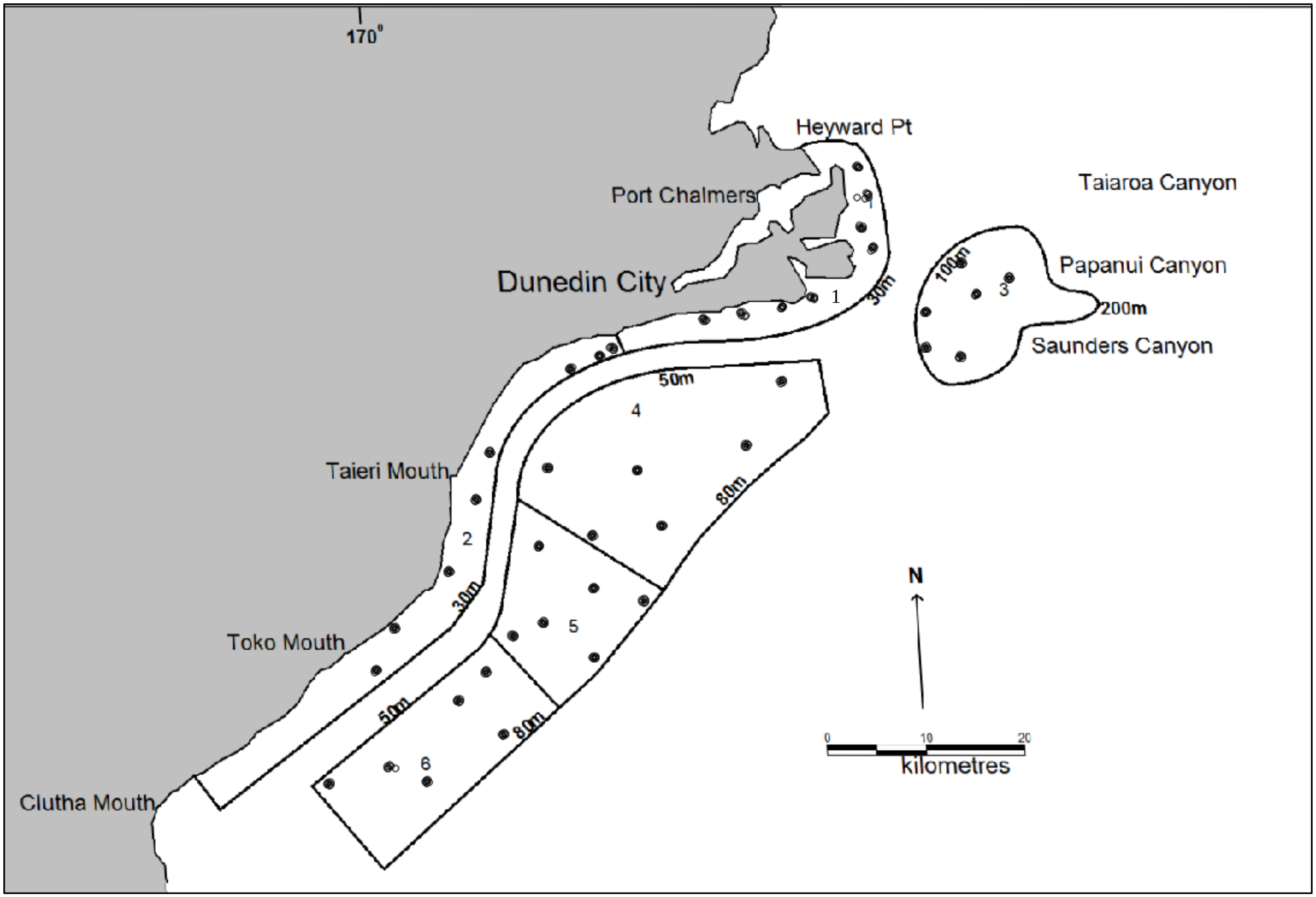


Figure 1: Sites surveyed in the 2013 south Otago random stratified site potting survey.

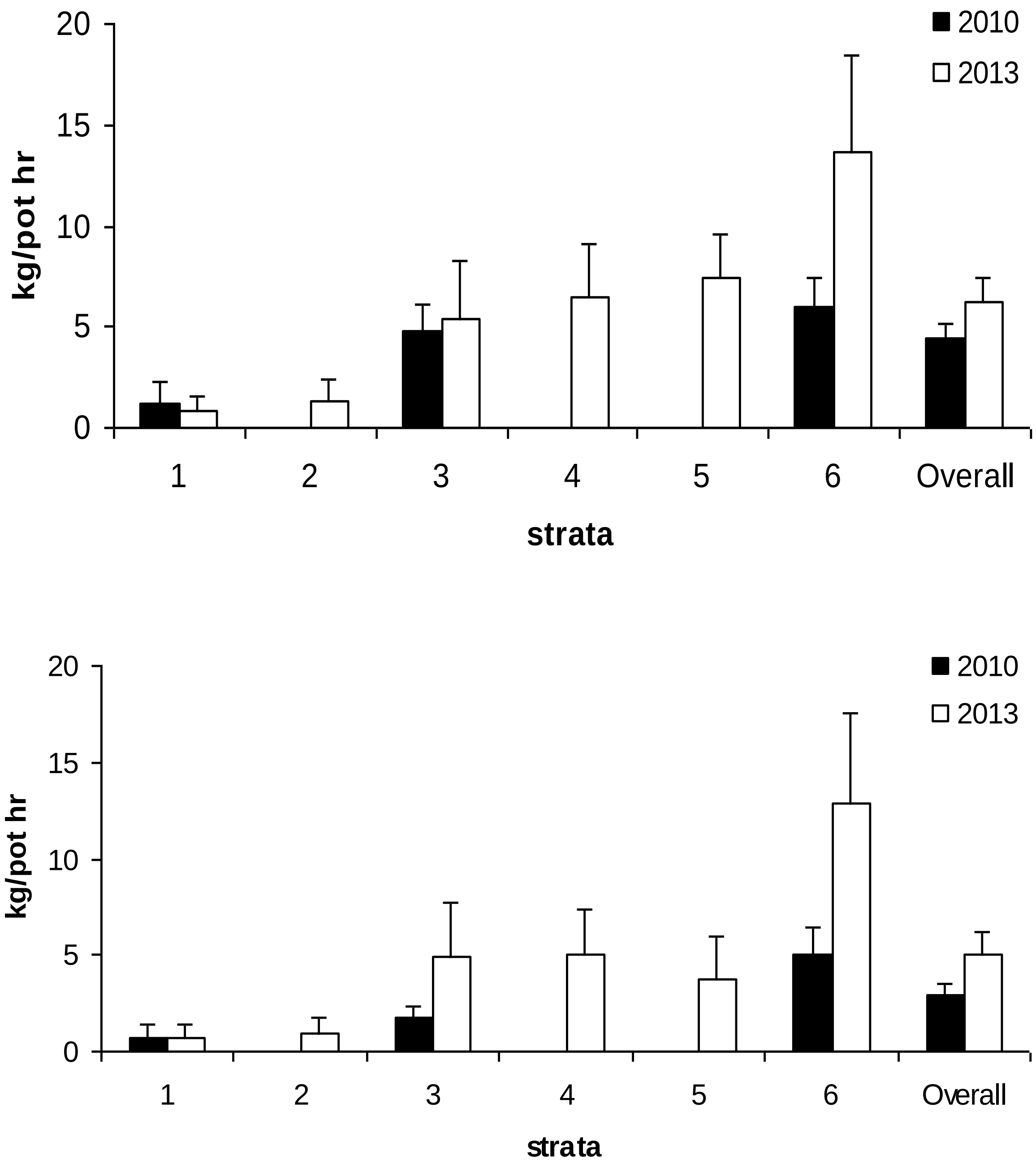


Figure 2: Catch rates (kg.pot^{-1}) and 95% confidence intervals for all blue cod (above) and those 30 cm and over (below) from the 2010 and 2013 south Otago random site survey. Strata and sites are shown in Figure 1.

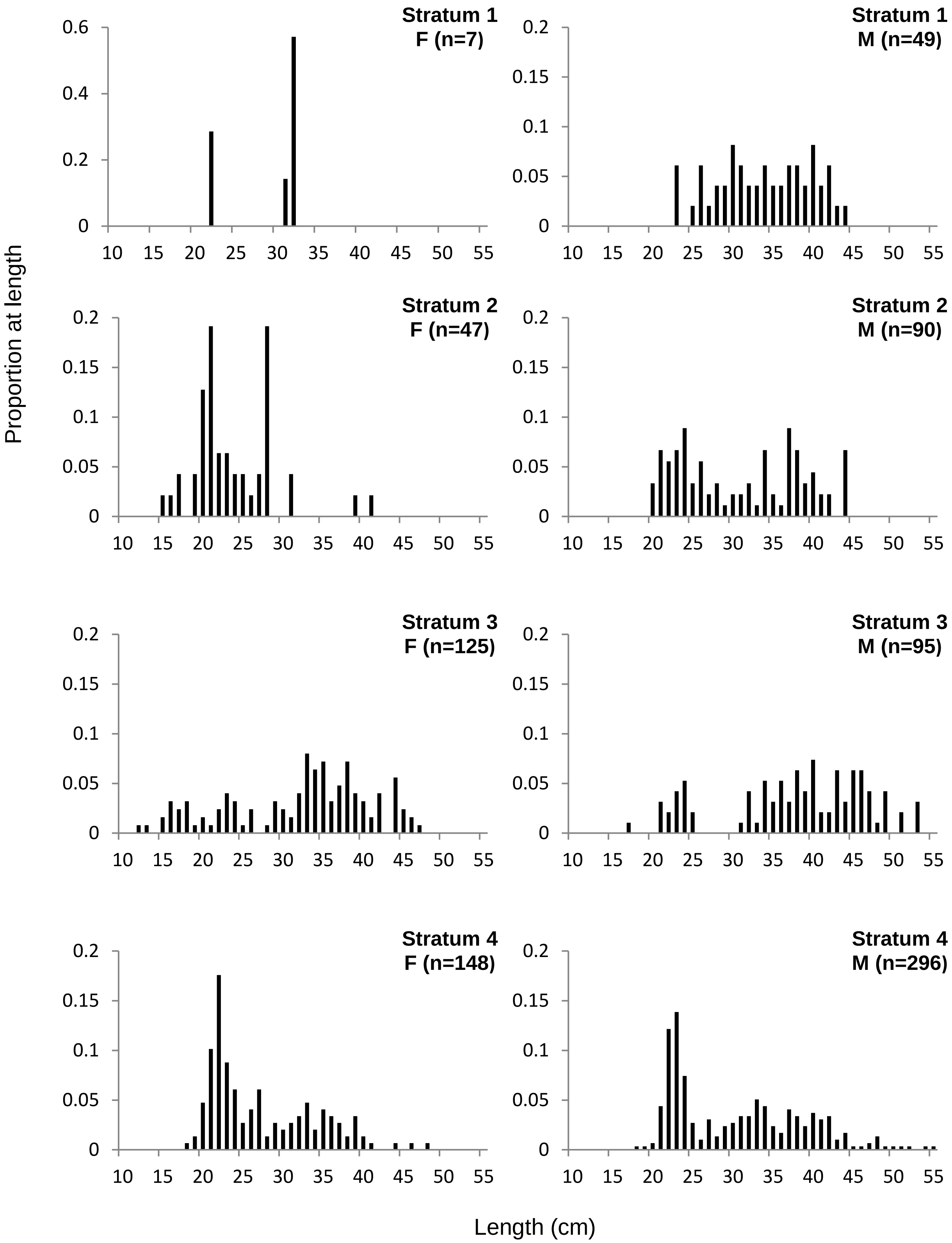


Figure 3: Unscaled proportion length frequency distributions by sex within stratum for the 2013 south Otago survey. Length frequency distributions by sex for both the inshore (all strata except stratum 3) and offshore (stratum 3 only) areas of the 2013 south Otago survey are also shown. Proportions for each sex within each stratum sum to 1. Strata are shown in Figure 1.

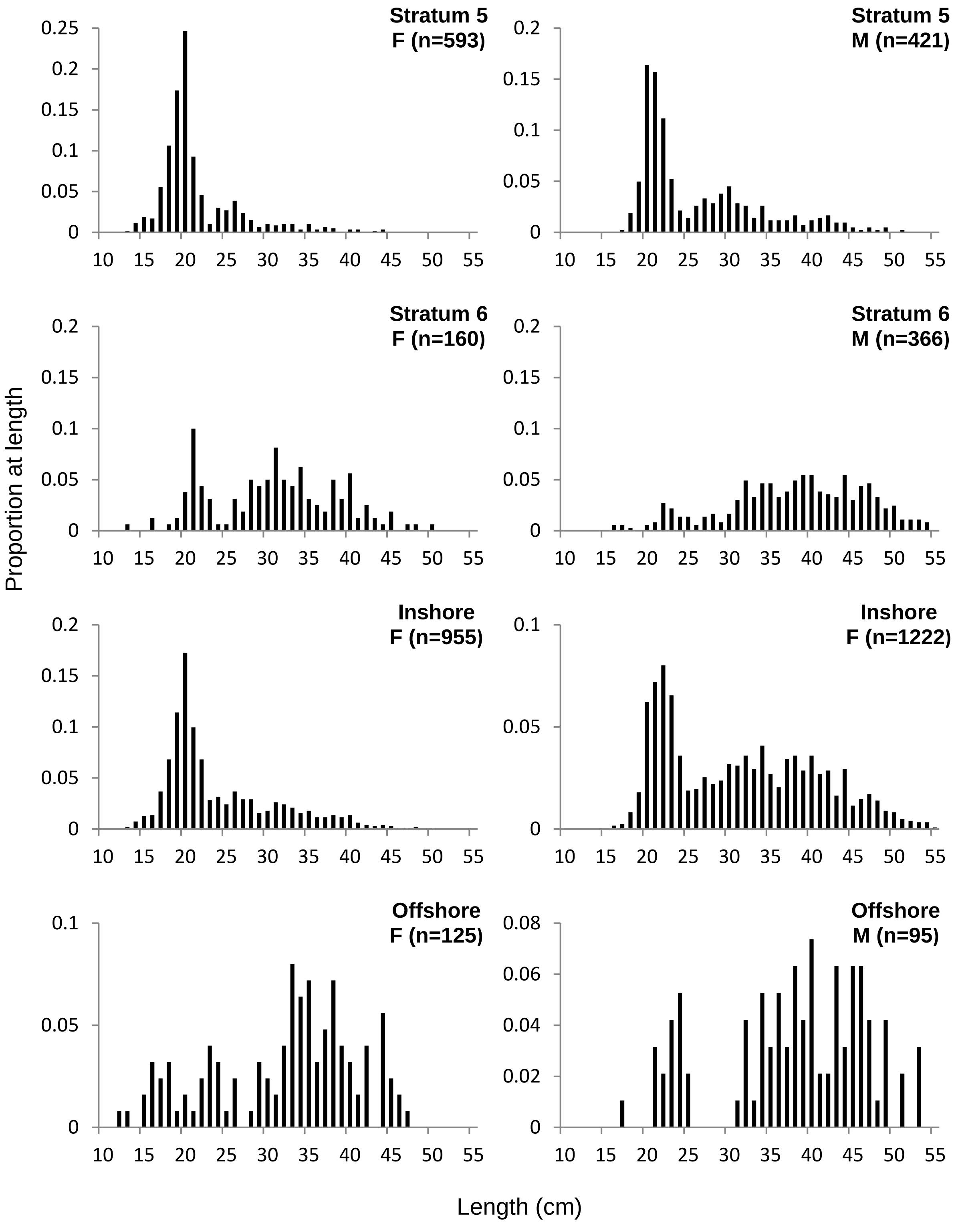


Figure 3 – ***continued***

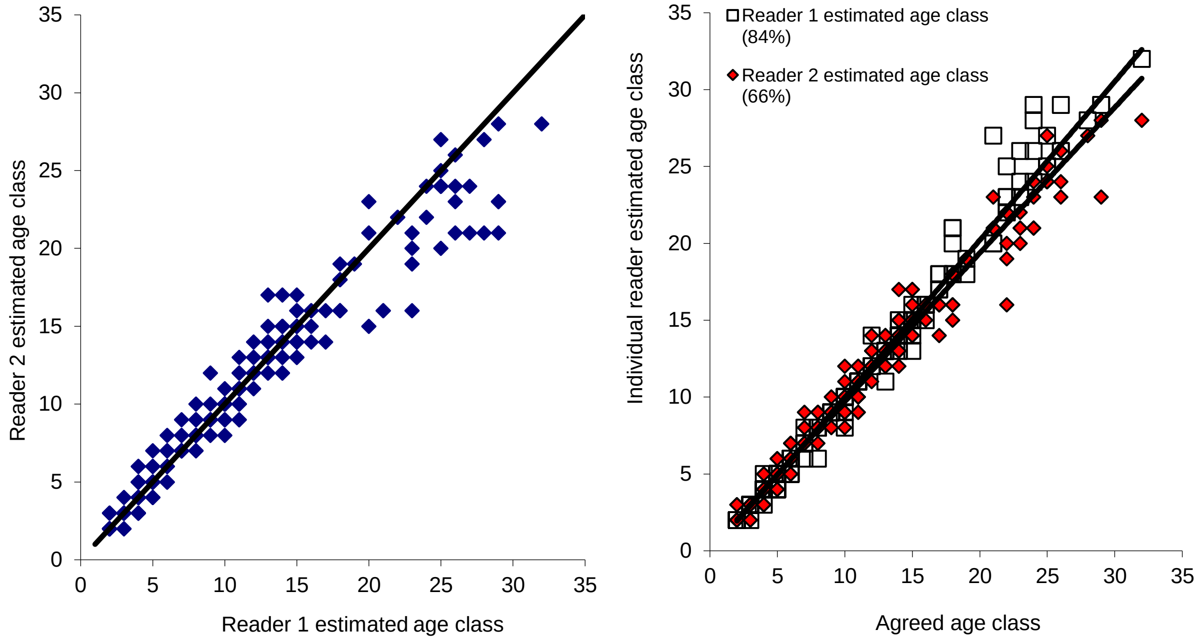


Figure 4: Inshore strata (excluding stratum 3) of the south Otago 2013 survey comparison of individual reader age class estimates from otoliths (n=305), on the left plotted against each other with the 1:1 line plotted (solid) fitted. In the right panel the agreed age class estimates is plotted against the readers' age class estimates with a polynomial trend line fitted for each reader.

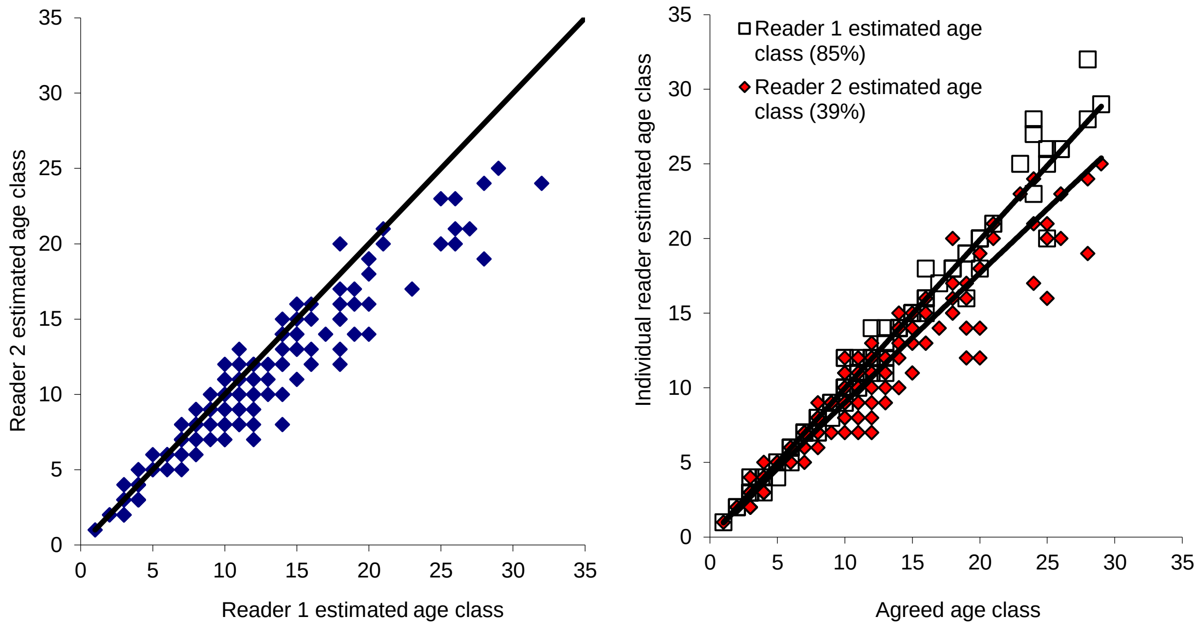


Figure 5: Offshore stratum (stratum 3 only) of the north Otago 2013 survey comparison of individual reader age class estimates from otoliths (n=200), on the left plotted against each other with the 1:1 line plotted (solid) fitted. In the right panel the agreed age class estimates is plotted against the readers' age class estimates with a polynomial trend line fitted for each reader.

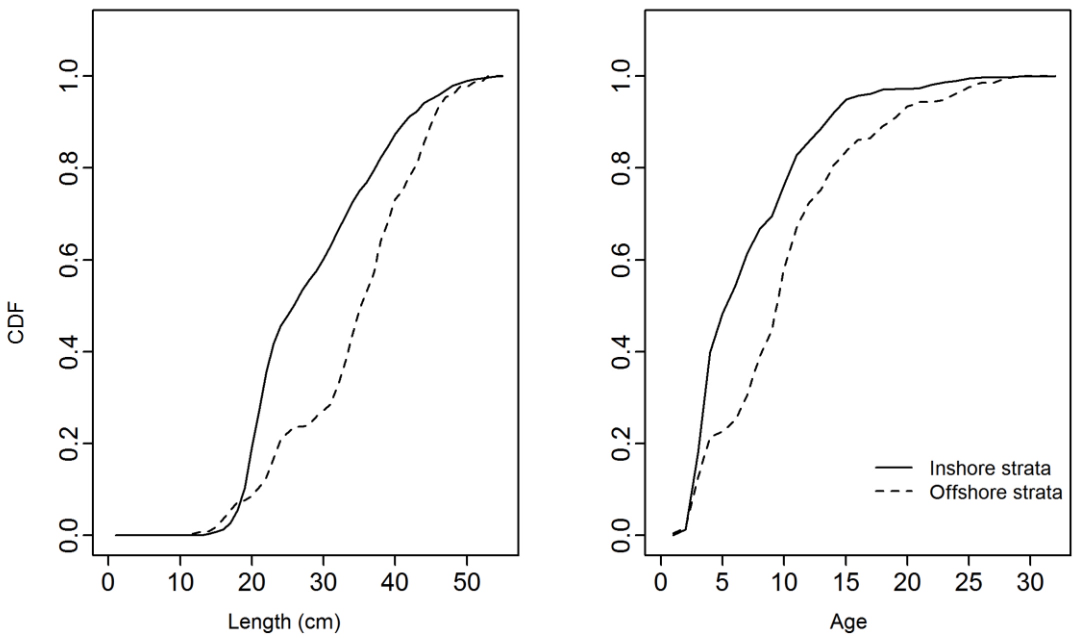


Figure 6: Cumulative distributions for length and age of blue cod for the 2013 south Otago inshore strata and offshore stratum.

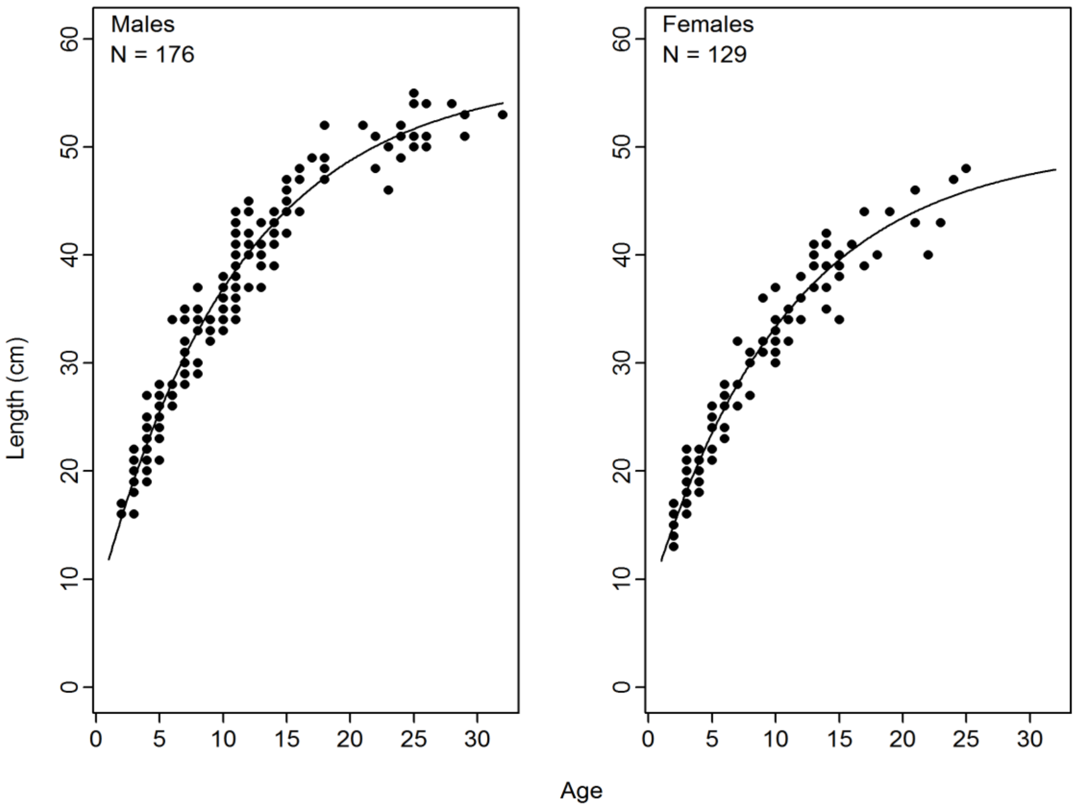


Figure 7: Observed age and length data by sex for inshore strata (excluding stratum 3) of the 2013 South Otago survey. Von Bertalanffy growth models, fitted to the data, are also shown.

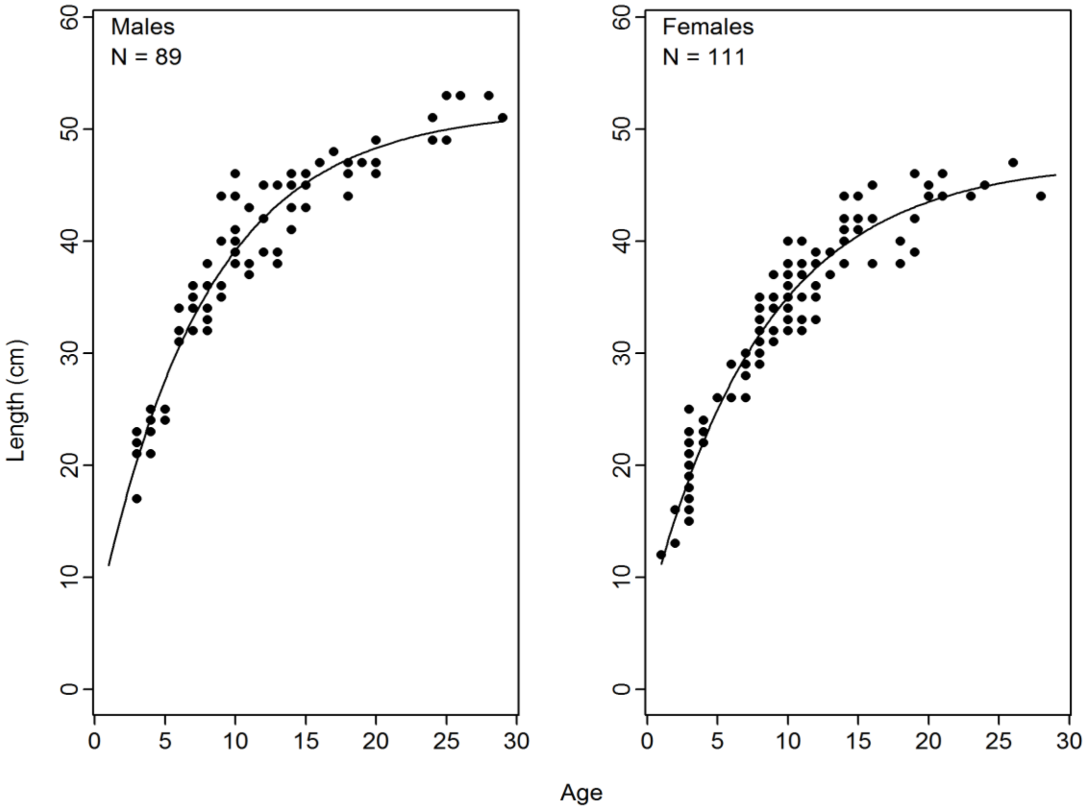


Figure 8: Observed age and length data by sex for the offshore stratum (3) of the 2013 South Otago survey. Von Bertalanffy growth models, fitted to the data, are also shown.

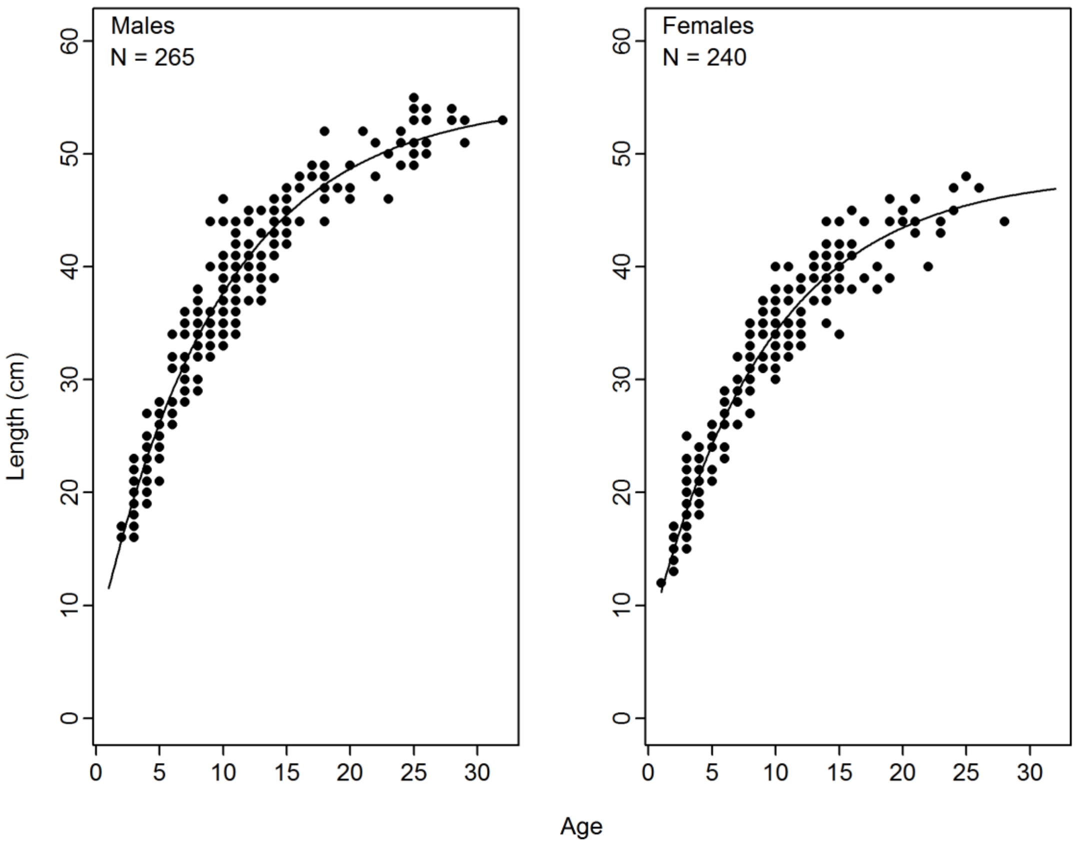


Figure 9: Observed age and length data by sex for all strata of the 2013 south Otago survey. Von Bertalanffy growth models, fitted to the data, are also shown.

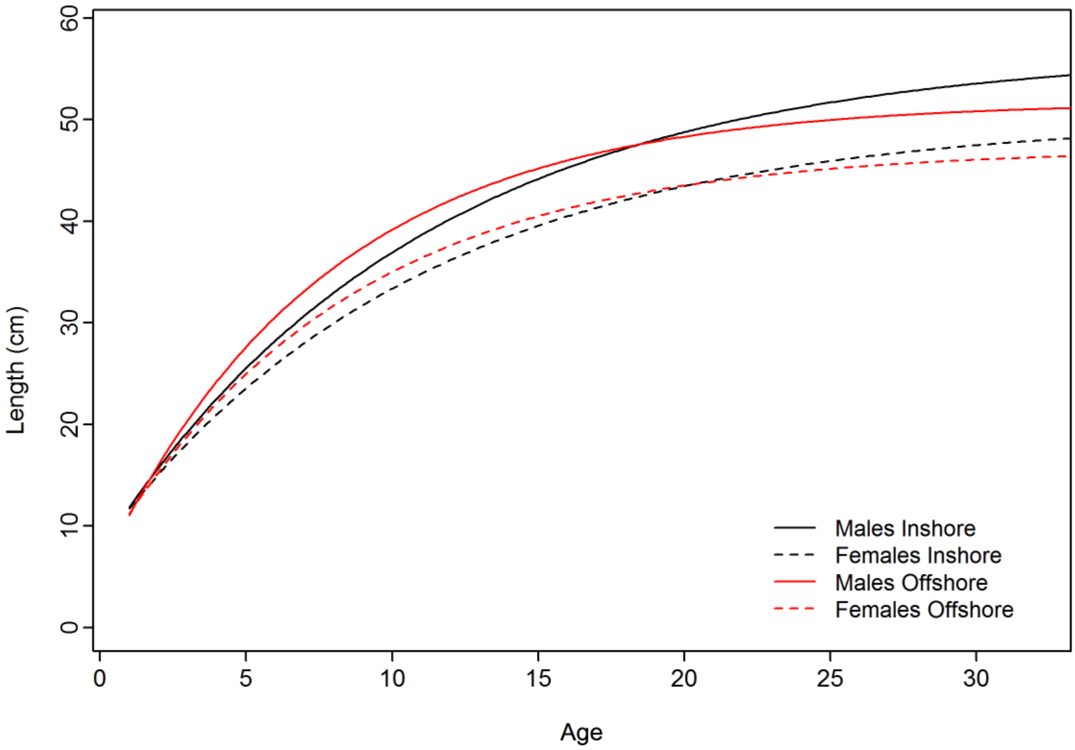


Figure 10: Comparison of inshore and offshore male and female von Bertalanffy growth curves.

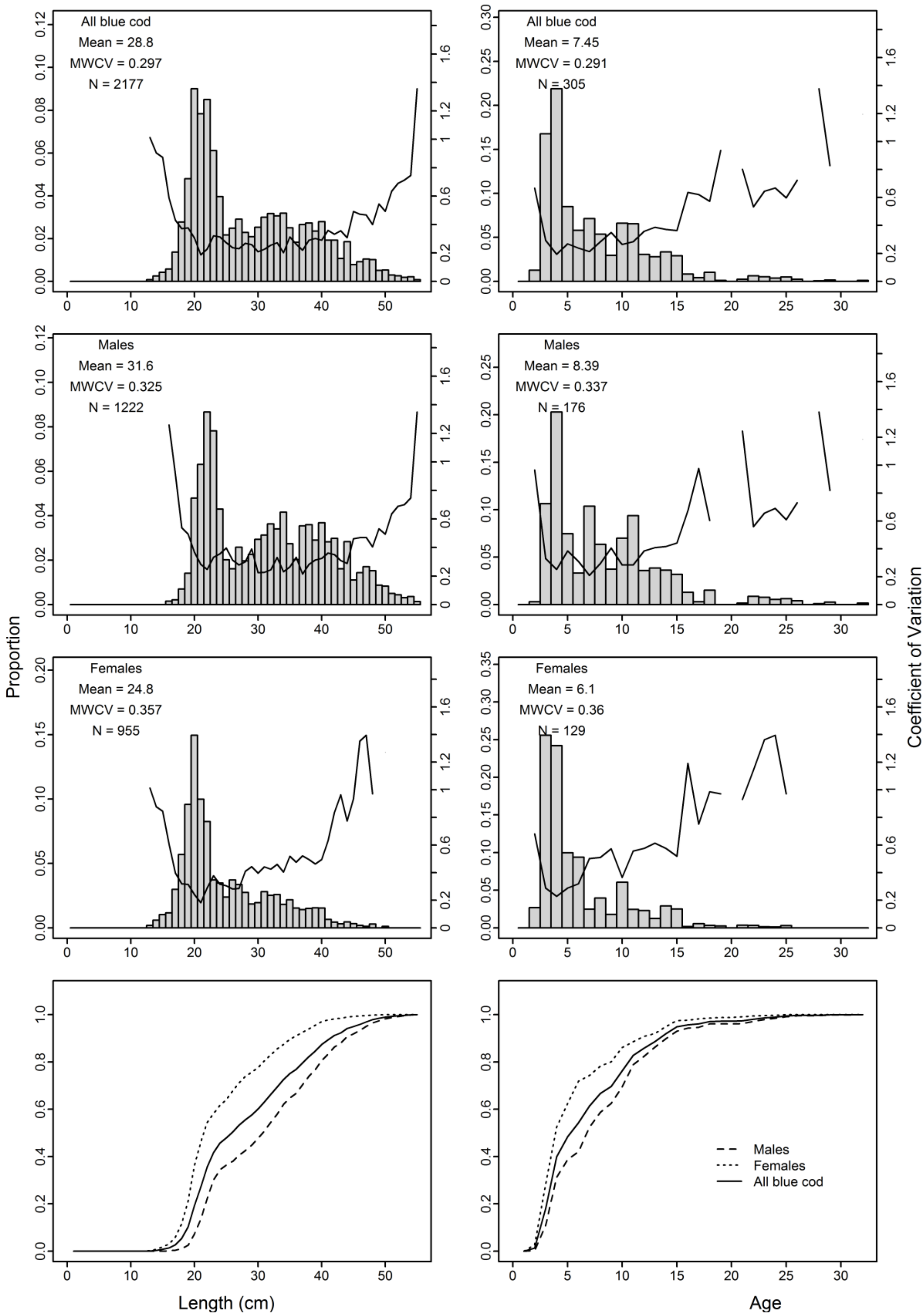


Figure 11: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for inshore strata (excluding stratum 3) of the 2013 South Otago survey. MWCV, mean weighted coefficient of variation.

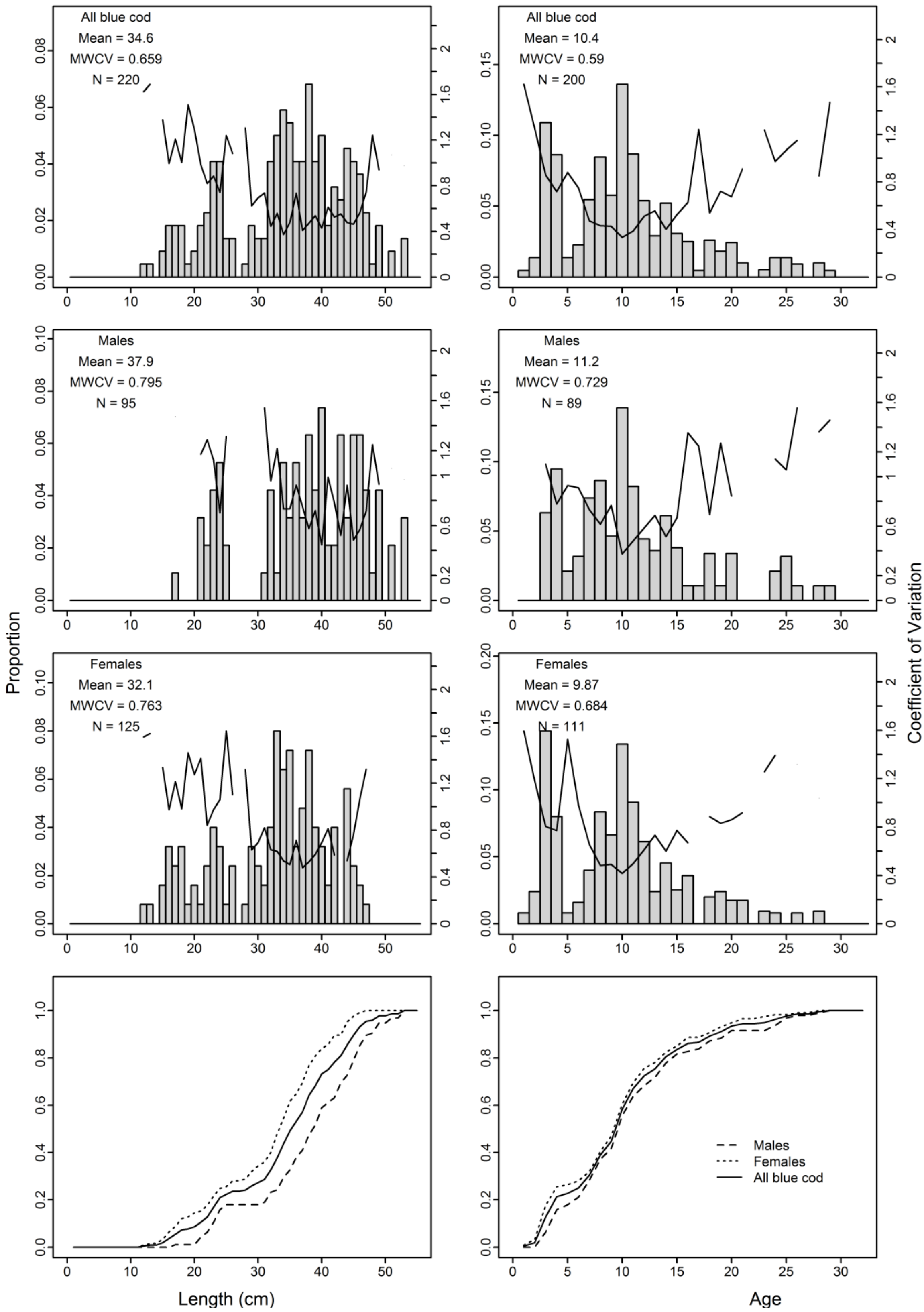


Figure 12: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for the offshore stratum (3) of the 2013 South Otago survey. MWCV, mean weighted coefficient of variation.

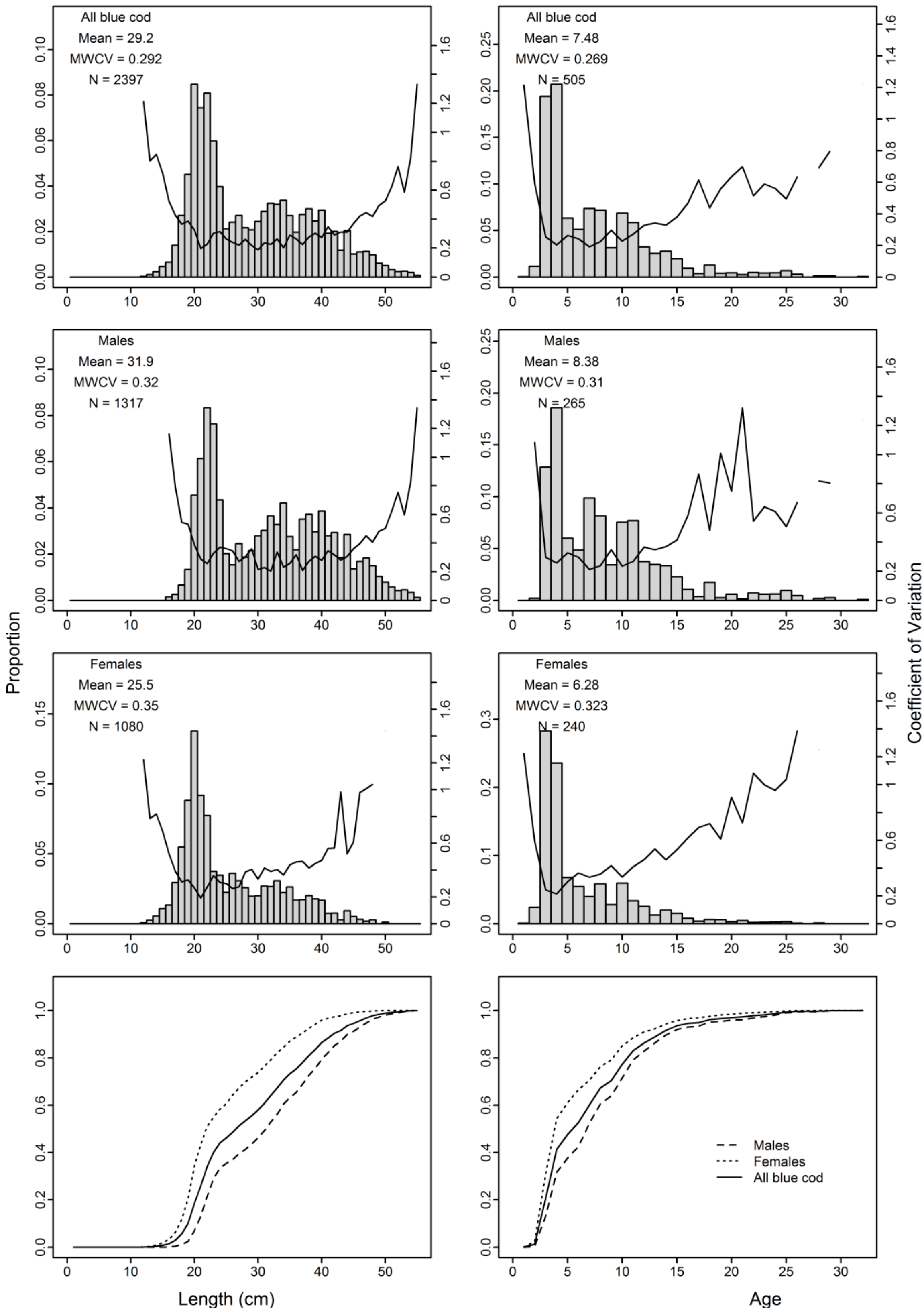


Figure 13: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata of the 2013 South Otago survey. MWCV, mean weighted coefficient of variation.

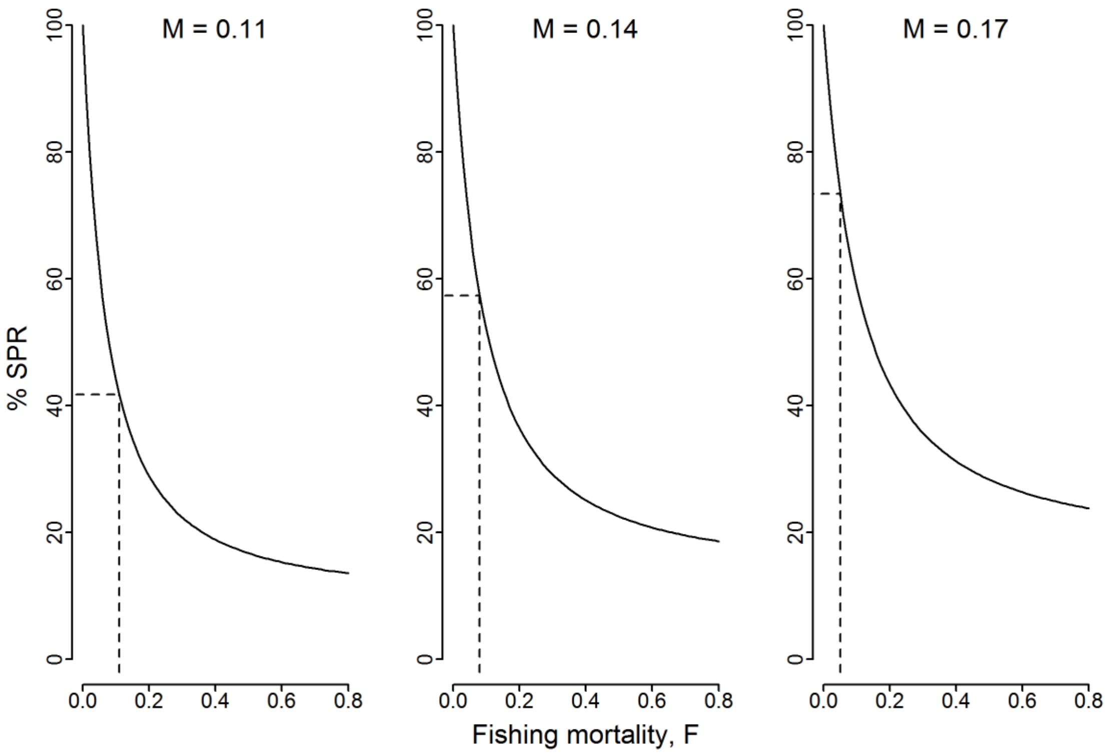


Figure 14: The ratio of spawner per recruit (SPR) relative to unfished SPR (%SPR) as a function of fishing mortality for the inshore strata (excluding stratum 3) of the 2013 South Otago survey at three values of M (0.11, 0.14, 0.17), assuming that the age at recruitment to the fishery is 9.

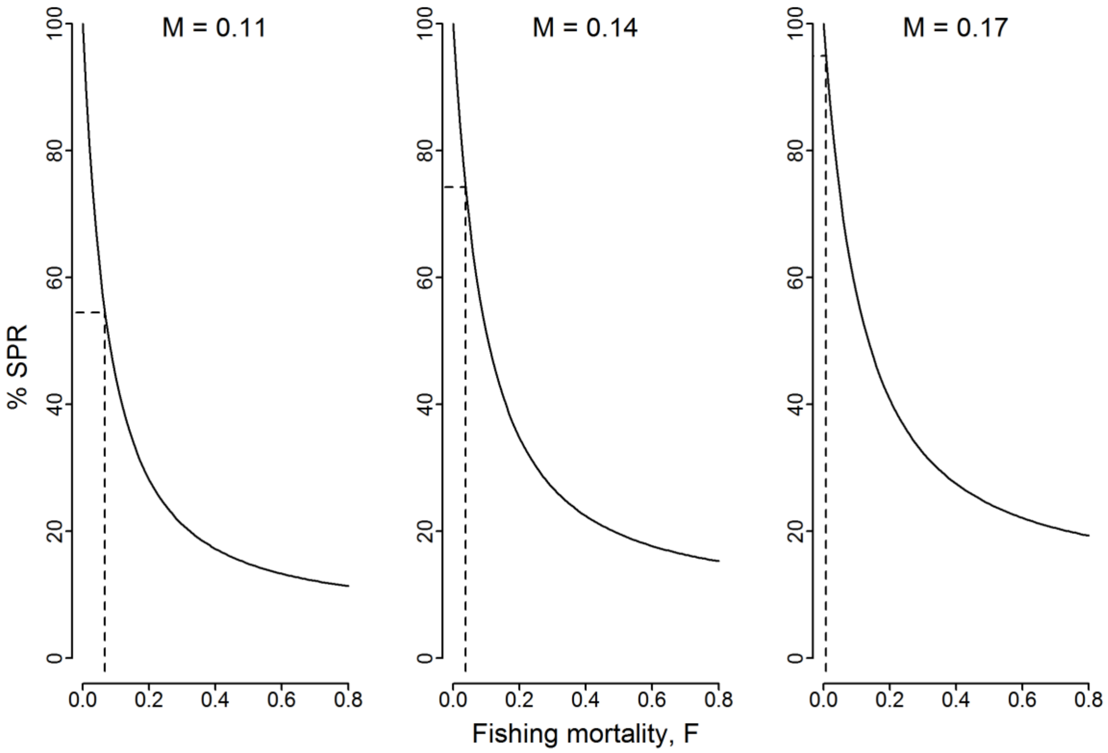


Figure 15: The ratio of spawner per recruit (SPR) relative to unfished SPR (%SPR) as a function of fishing mortality for the offshore stratum (3) of the 2013 South Otago survey at three values of M (0.11, 0.14, 0.17), assuming that the age at recruitment to the fishery is 8.

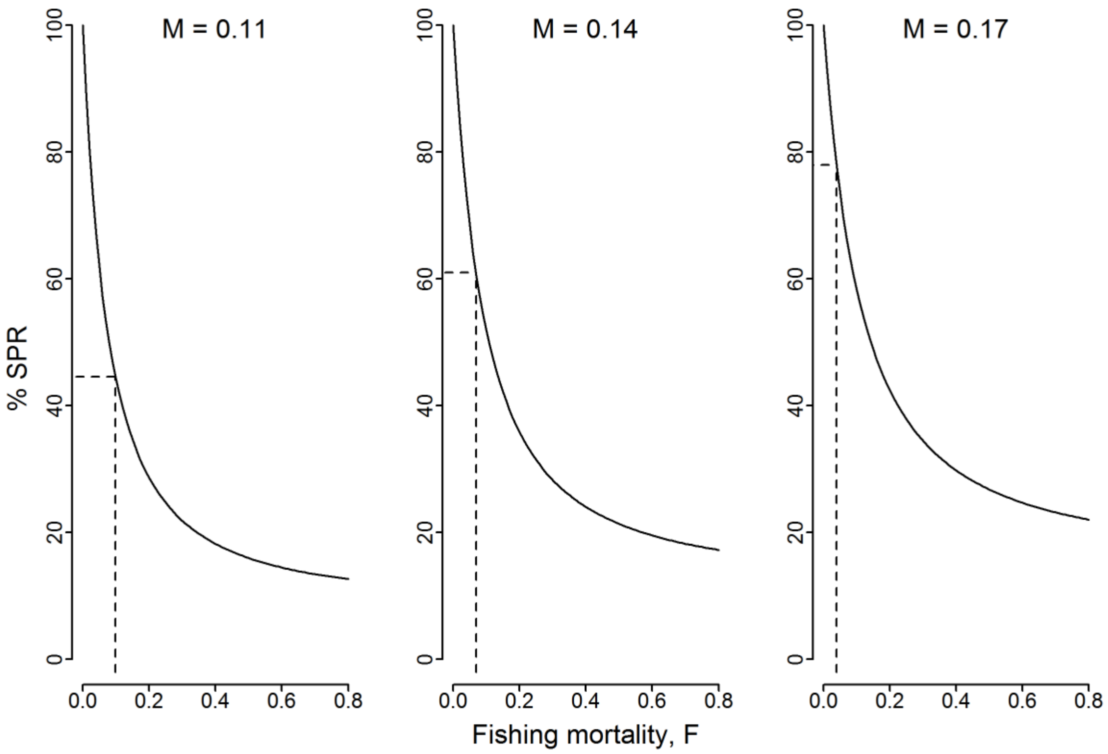


Figure 16: The ratio of spawner per recruit (SPR) relative to unfished SPR (%SPR) as a function of fishing mortality for all strata of the 2013 south Otago survey at three values of M (0.11, 0.14, 0.17), assuming that the age at recruitment to the fishery is 8.

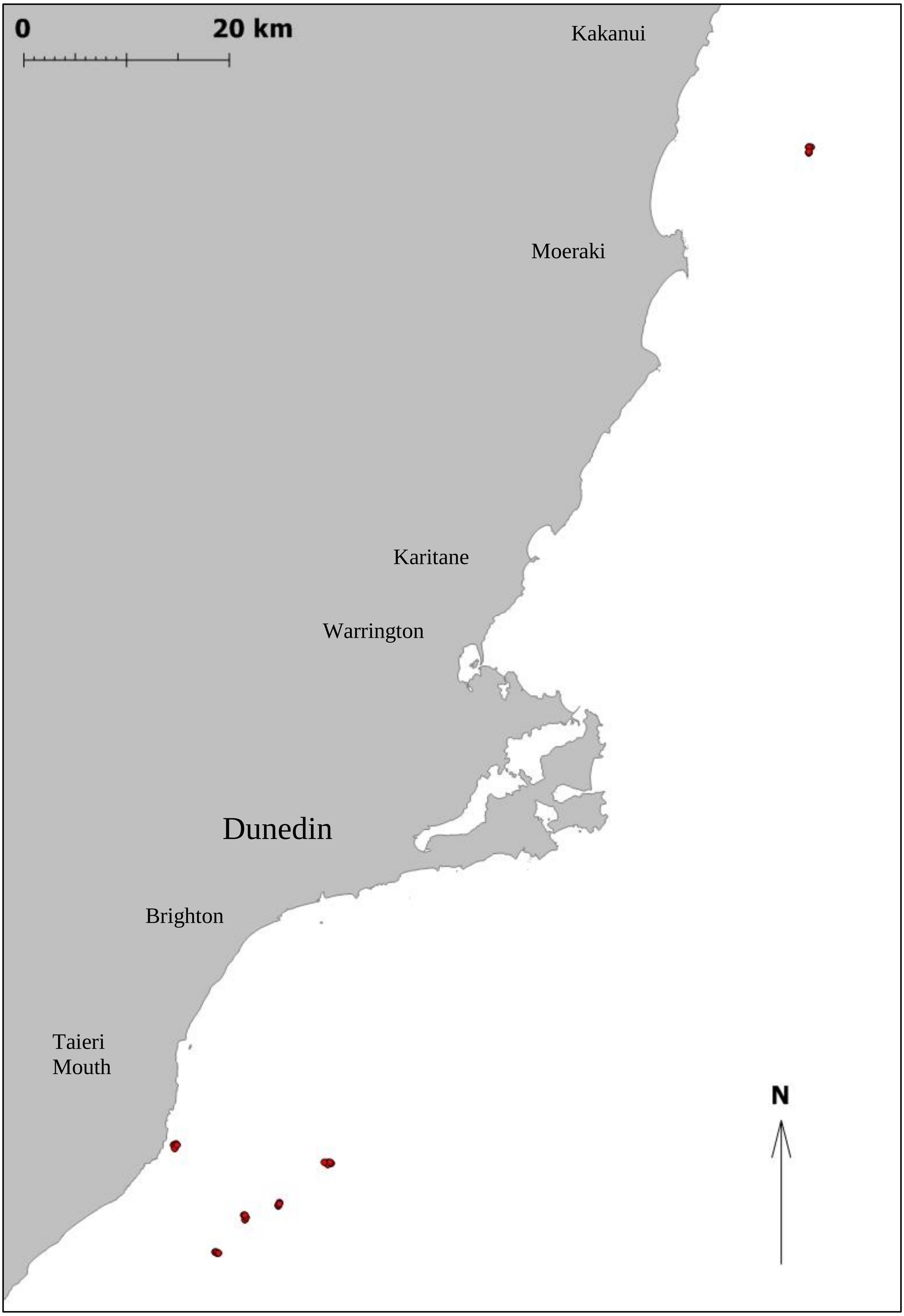


Figure 17: Six sites with DUV transects surveyed prior to pots in the 2013 north and south Otago blue cod potting surveys.

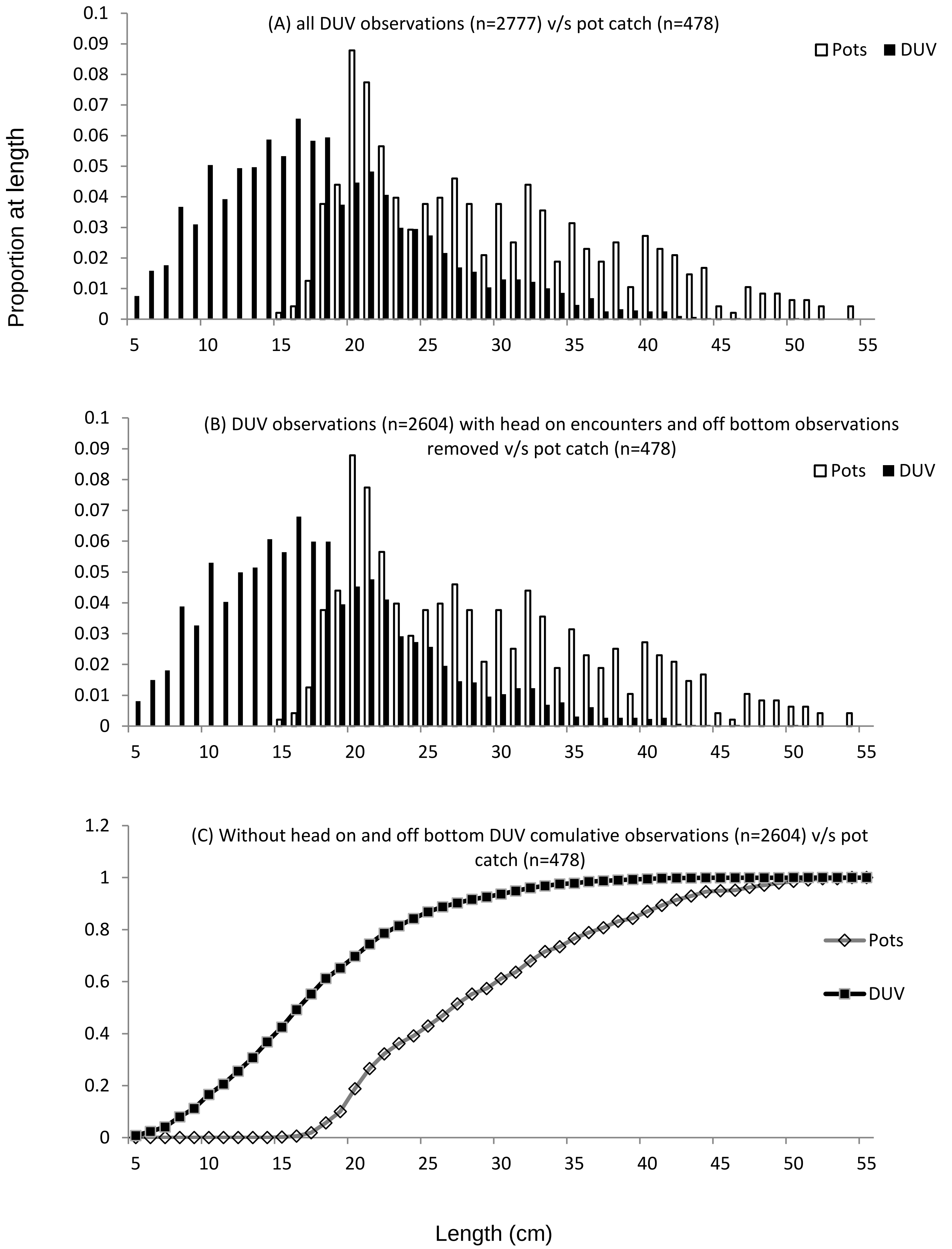


Figure 18: (A) –All measured video observations of blue cod sizes plotted against sizes from concurrent pot catch. (B) – Blue cod sizes from video observations without head-on body orientation to camera or off bottom observations plotted against sizes from pot catch. (C)– Cumulative frequency distribution without video head-on body orientation or off bottom observations.

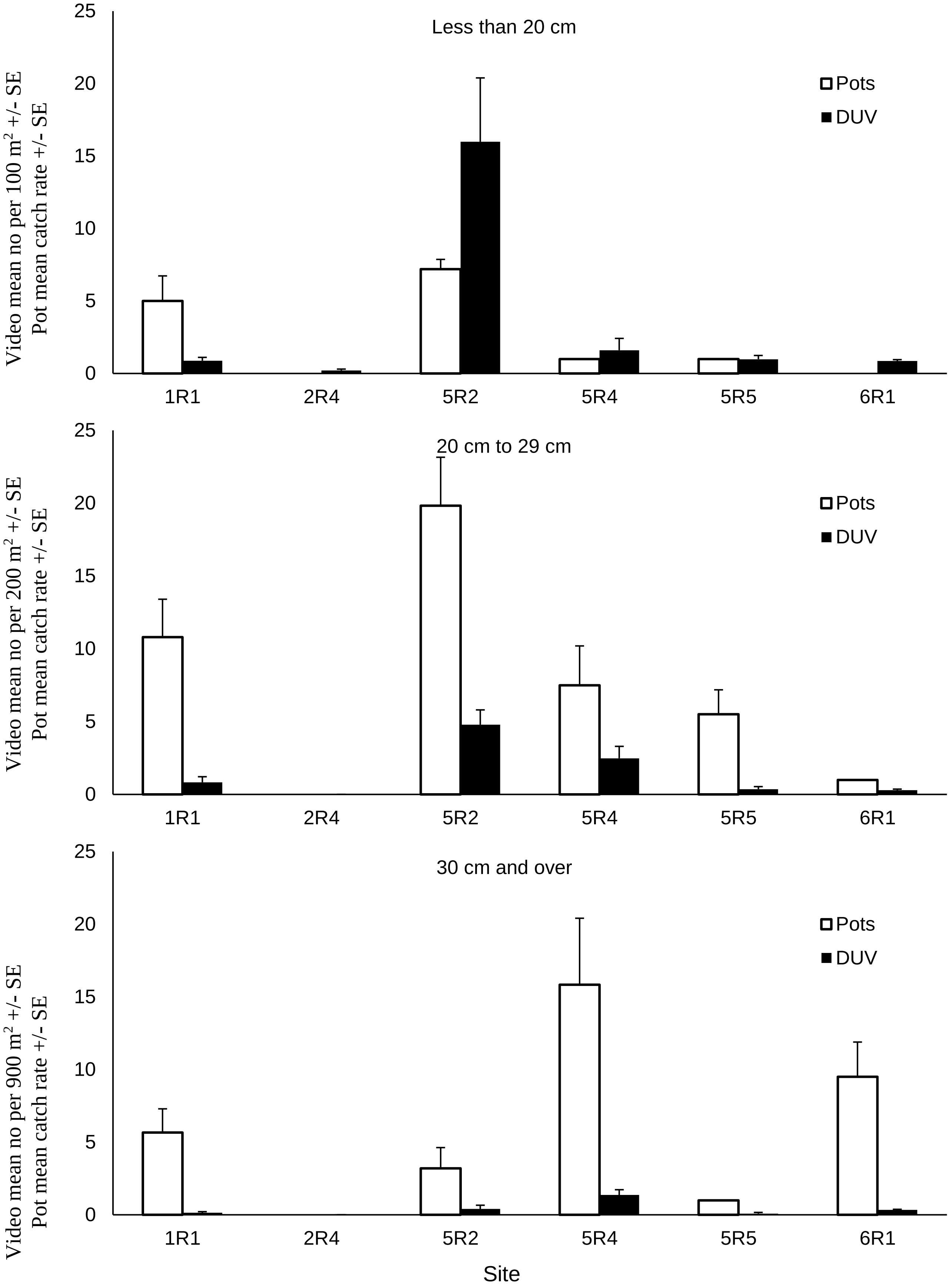


Figure 19: Mean site relative abundance (Number.pot^{-1}) from pots versus the equivalent mean site density estimates from the area swept video method for three size classes of blue cod, less than 20 cm (top), 20–29 cm (centre), 30 cm and over (bottom). Error bars are ± one standard error.

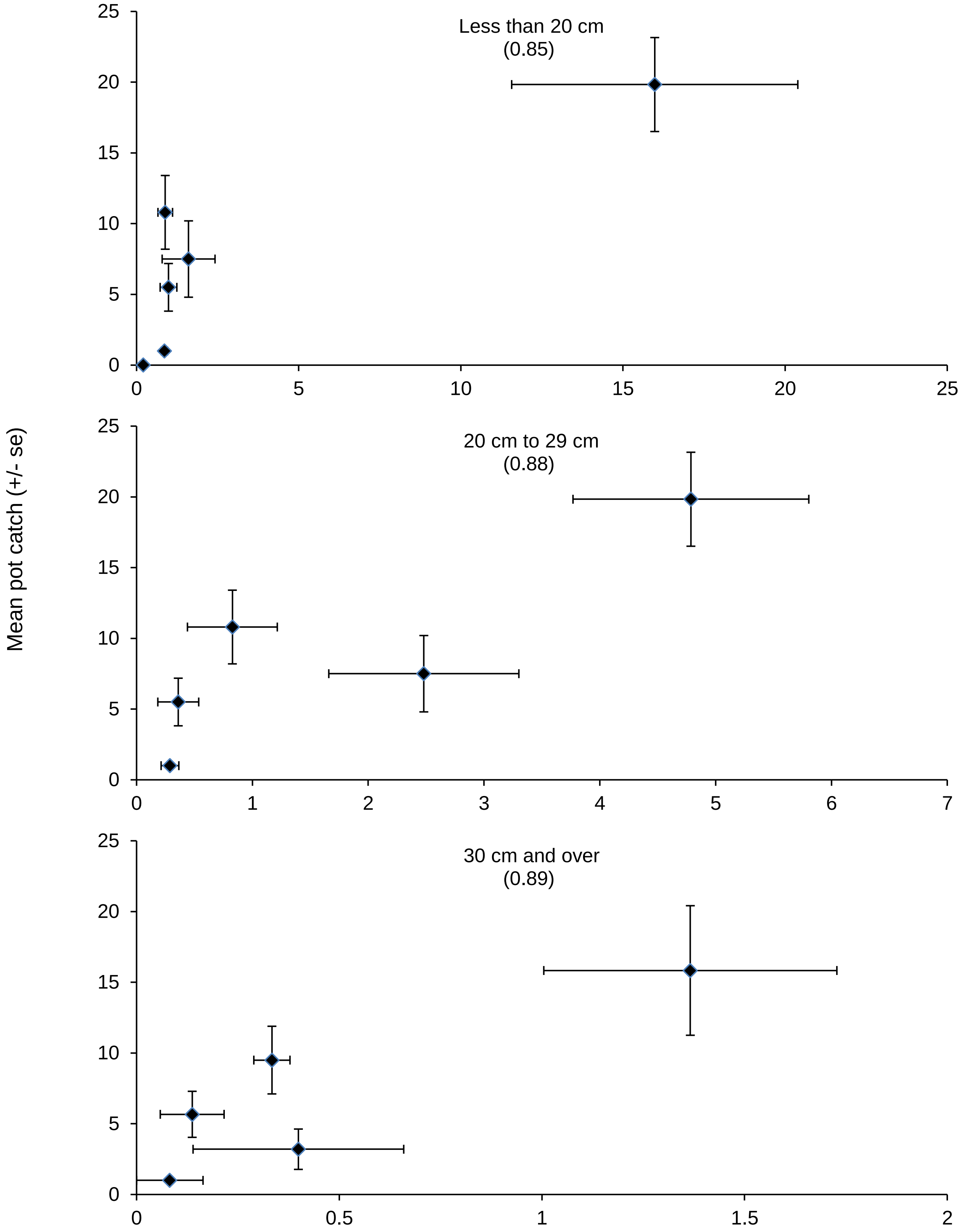
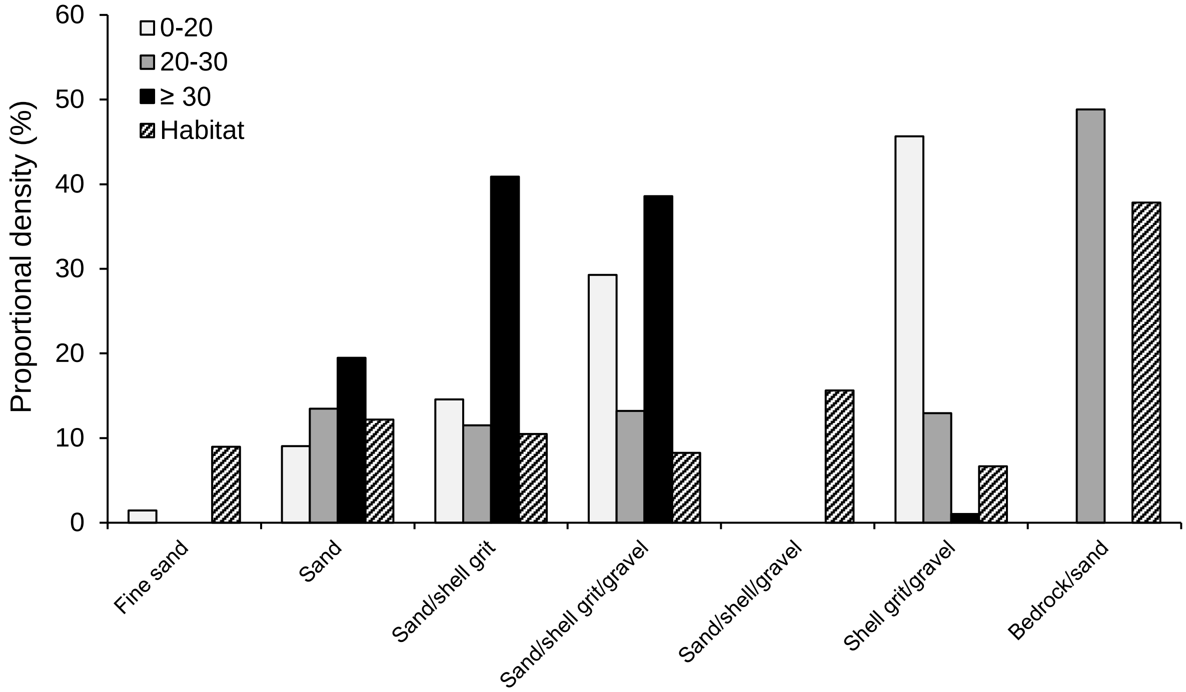


Figure 20: Mean density versus catch rate (kg.pot^{-1}) for three size classes of blue cod dual surveyed with DUV and pots, error bars are ± one standard error. The correlation coefficient is shown in brackets below the size class title.



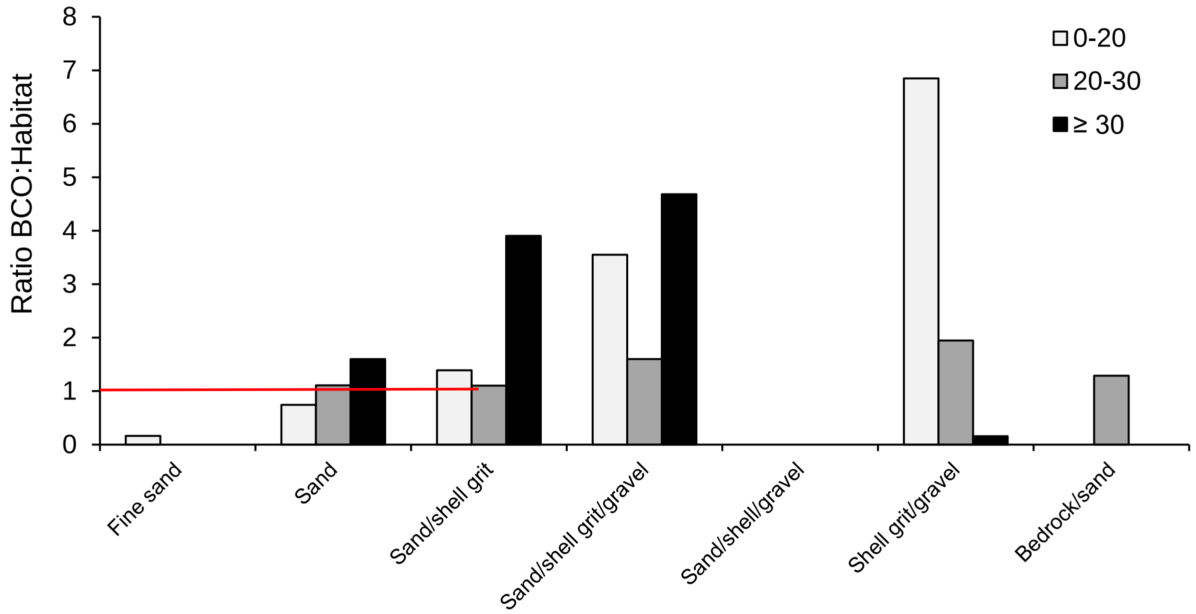


Figure 21: Proportion of blue cod (three size classes) and fish-independent DUV observations of primary substrate from all sites (top). The ratio of the proportion of blue cod-associated primary substrate and the fish-independent substrate recorded by the video is shown in the bottom figure with a line drawn at a 1:1 ratio.

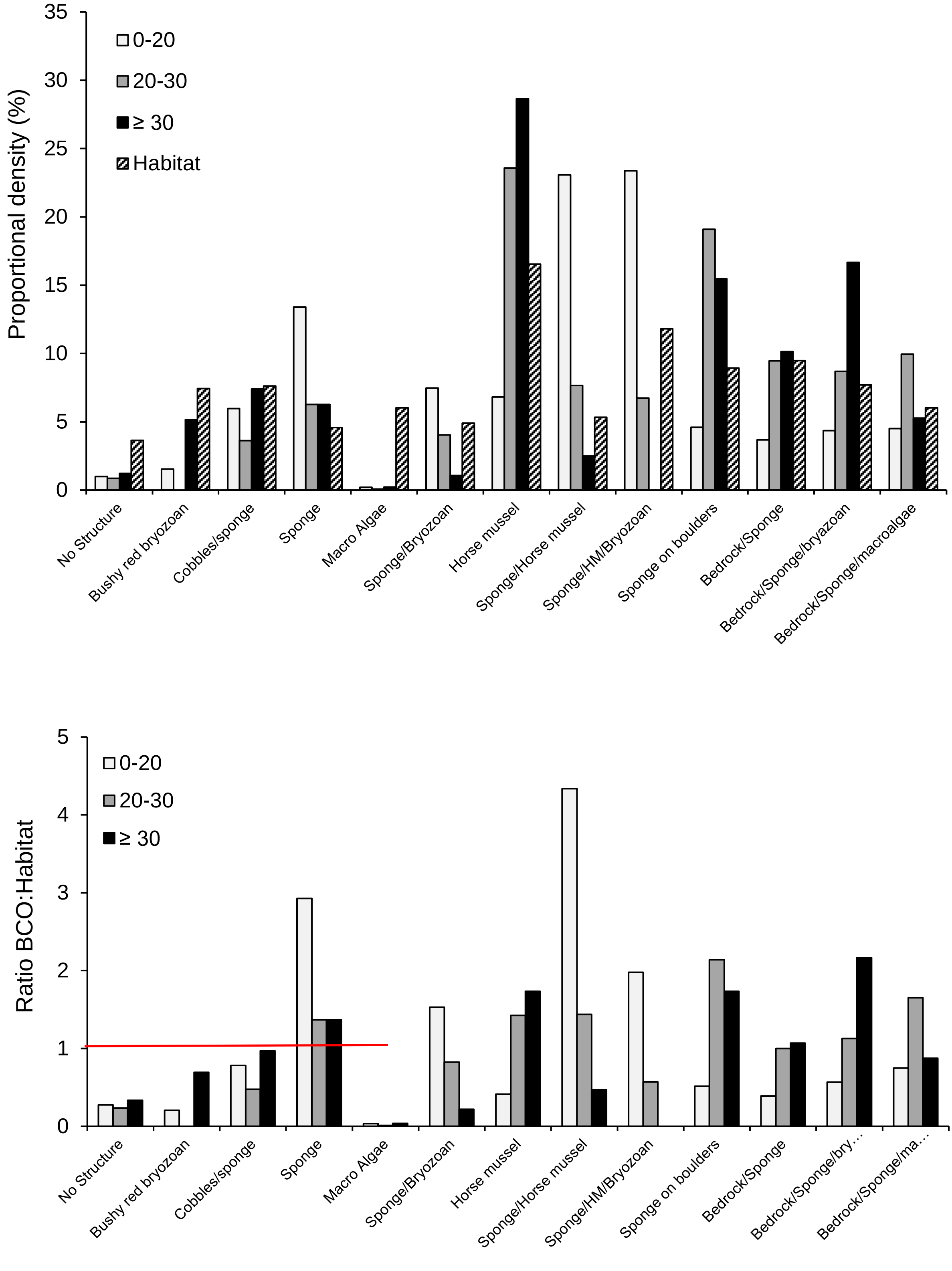


Figure 22: Proportion of blue cod (three size classes) and fish-independent DUV observations of secondary structure from all sites (top). The ratio of the proportion of blue cod-associated primary substrate and the fish-independent substrate recorded by the video is shown in the bottom figure with a line drawn at a 1:1 ratio.

Appendix 1: Terminology used in potting surveys.

In this report we use the terms defined in the blue cod potting survey manual (Beentjes & Francis 2011)

Site A geographical location near to which sampling may take place during a survey. A site may be either fixed or random (see below). A site may be specified as a latitude and longitude or a section of coastline (for the latter, use the latitude and longitude at the centre of the section).

Fixed site A predetermined site within a given stratum, that has a fixed location (single latitude and longitude or the centre point location of a section of coastline) and is available to be used repeatedly on subsequent surveys in that area. Fixed sites are known fishing spots identified by local fishers. Which fixed sites are used in a particular survey is determined by random selection from all available fixed sites in each stratum. Fixed sites are sometimes referred to as an index site or a fisher-selected site**.**

Random site A site that can have any location (single latitude and longitude) generated randomly from within a stratum, given the constraints of proximity to other selected sites for a specific survey.

Site label An alphanumeric label of no more than 4 characters unique within a survey time series. A site label identifies each site and also specifies which stratum it lies in. Fixed site labels are constructed by concatenating the stratum code with an alpha label (A–Z) that is unique within that stratum. Thus, sites within stratum 2 could be labelled 2A, 2B, and sites in stratum 3 could be labelled 3A, 3B etc. Note that fixed site label remain constantly fixed to that location for all surveys. In contrast, random sites are regenerated for each survey and use a numeric label based on the order in which they were randomly generated, followed by the letter R and then concatenated with the stratum code. Thus, sites within stratum 2 could be labelled 2R1, 2R3, and sites in stratum 3 could be labelled 3R1, 3R2 etc.

Set A group of pots deployed in the vicinity of a selected site in a specific survey. The pots are set in a cluster or linear configuration.

Set number A number assigned to the each set within a survey. Set numbers are defined sequentially in the order fished. Thus, any set within a survey is uniquely defined by a trip code and set number. Note that the set number is not recorded in the *trawl* database in isolation, but is entered as part of attribute *station_no*in table *t_station*.

Station The position (latitude and longitude) at which a single pot (or other fishing gear) is deployed at a site during a survey, i.e. it is unique for the trip.

Pot number Pots are numbered sequentially (1 to 6) in the order they are placed during a set.

Station number A number which uniquely identifies each station within a survey. The station number is formed by concatenating the set number with the pot number. Thus, pot 4 in set 23 would be station number 234. This convention is important in enabling users of the *trawl* database to determine whether two pots are from the same set.

Pot placement There are two types of pot placement 1) Directed, where the position of each pot is directed by the skipper using local knowledge and the vessel SONAR to locate a suitable area of reef/cobble or biogenic habitat (this is how pots are set at fixed sites). 2) Systematic, where the position of each pot is determined from a fixed pattern set systematically around a site centre point. The pots are set blind with no knowledge of the bottom type (this is how pots are set at random sites).

Appendix 2: Summary of survey pot lift station data, south Otago 2013.

								Catch of blue cod	
Set	Date	Phase	Stratum	Site	Depth (m)	Time set	Pot	(kg)	Number
1	5-Apr-13	1	2	R3	23	8:02	6	1.4	2
1	5-Apr-13	1	2	R3	23	8:07	1	4.3	7
1	5-Apr-13	1	2	R3	22	8:13	3	4.5	23
1	5-Apr-13	1	2	R3	21	8:18	5	8.1	38
1	5-Apr-13	1	2	R3	22	8:24	2	0	0
1	5-Apr-13	1	2	R3	23	8:29	4	0	0
2	5-Apr-13	1	2	R3	30	10:20	4	0	0
2	5-Apr-13	1	2	R3	32	10:25	2	0	0
2	5-Apr-13	1	2	R3	31	10:30	5	0	0
2	5-Apr-13	1	2	R3	30	10:35	3	0	0
2	5-Apr-13	1	2	R3	32	10:39	1	0	0
2	5-Apr-13	1	2	R3	30	10:44	6	0	0
3	6-Apr-13	1	2	R5	26	9:30	1	0	0
3	6-Apr-13	1	2	R5	27	9:35	5	0	0
3	6-Apr-13	1	2	R5	26	9:40	6	0	0
3	6-Apr-13	1	2	R5	26	9:45	4	0	0
3	6-Apr-13	1	2	R5	26	9:50	3	0	0
3	6-Apr-13	1	2	R5	26	9:55	2	0	0
4	6-Apr-13	1	2	R6	17	11:17	2	0	0
4	6-Apr-13	1	2	R6	19	11:21	3	0	0
4	6-Apr-13	1	2	R6	20	11:26	4	0	0
4	6-Apr-13	1	2	R6	18	11:30	6	0	0
4	6-Apr-13	1	2	R6	16	11:35	5	0	0
4	6-Apr-13	1	2	R6	16	11:40	1	0	0
5	6-Apr-13	1	2	R4	22	13:25	1	0	0
5	6-Apr-13	1	2	R4	23	13:25	5	0	0
5	6-Apr-13	1	2	R4	22	13:30	6	0	0
5	6-Apr-13	1	2	R4	22	13:34	4	0	0
5	6-Apr-13	1	2	R4	21	13:37	3	0	0
5	6-Apr-13	1	2	R4	21	13:40	2	0	0
6	7-Apr-13	1	2	R4	25	14:17	2	0	0
6	7-Apr-13	1	2	R4	23	14:21	3	0	0
6	7-Apr-13	1	2	R4	19	14:24	4	0	0
6	7-Apr-13	1	2	R4	19	14:28	6	0	0
6	7-Apr-13	1	2	R4	20	14:30	1	0	0
6	7-Apr-13	1	2	R4	23	14:32	5	0	0
7	8-Apr-13	1	4	R3	40	11:47	5	0	0
7	8-Apr-13	1	4	R3	40	11:50	1	0	0
7	8-Apr-13	1	4	R3	40	11:54	6	0	0
7	8-Apr-13	1	4	R3	41	11:58	4	0	0
7	8-Apr-13	1	4	R3	40	12:02	3	0	0
7	8-Apr-13	1	4	R3	40	12:05	2	0	0
8	8-Apr-13	1	5	R1	46	13:41	2	0	0
8	8-Apr-13	1	5	R1	45	13:44	3	0	0
8	8-Apr-13	1	5	R1	46	13:47	4	12.3	12

Set	Date	Phase	Stratum	Site	Depth (m)	Time set	Pot	Catch of blue cod (kg)	Number
8	8-Apr-13	1	5	R1	47	13:50	6	7.5	9
8	8-Apr-13	1	5	R1	46	13:54	1	0.9	1
8	8-Apr-13	1	5	R1	46	13:57	5	0	0
9	10-Apr-13	1	4	R5	58	12:54	1	31.9	30
9	10-Apr-13	1	4	R5	60	12:58	5	6.4	11
9	10-Apr-13	1	4	R5	57	13:02	2	0	0
9	10-Apr-13	1	4	R5	57	13:06	6	15.2	14
9	10-Apr-13	1	4	R5	58	13:10	4	15.5	14
9	10-Apr-13	1	4	R5	58	13:14	3	3.7	14
10	10-Apr-13	1	6	R4	61	13:56	3	8.6	11
10	10-Apr-13	1	6	R4	59	14:02	4	11.9	13
10	10-Apr-13	1	6	R4	60	14:07	6	11.4	16
10	10-Apr-13	1	6	R4	61	14:13	2	5	7
10	10-Apr-13	1	6	R4	61	14:17	5	7	13
10	10-Apr-13	1	6	R4	59	14:24	1	6.8	8
11	12-Apr-13	1	6	R2	61	8:05	1	13.5	11
11	12-Apr-13	1	6	R2	60	8:10	5	31.3	23
11	12-Apr-13	1	6	R2	57	8:15	2	20.8	18
11	12-Apr-13	1	6	R2	58	8:20	6	28.5	31
11	12-Apr-13	1	6	R2	58	8:25	4	38.9	27
11	12-Apr-13	1	6	R2	59	8:30	3	34.9	27
12	12-Apr-13	1	6	R5	31	11:04	3	0	0
12	12-Apr-13	1	6	R5	31	11:08	4	0	0
12	12-Apr-13	1	6	R5	30	11:12	6	0	0
12	12-Apr-13	1	6	R5	29	11:16	2	0	0
12	12-Apr-13	1	6	R5	29	11:20	5	0	0
12	12-Apr-13	1	6	R5	29	11:25	1	0	0
13	15-Apr-13	1	4	R4	58	9:08	2	0	0
13	15-Apr-13	1	4	R4	58	9:13	6	0	0
13	15-Apr-13	1	4	R4	57	9:18	4	0	0
13	15-Apr-13	1	4	R4	56	9:23	3	0	0
13	15-Apr-13	1	4	R4	56	9:28	1	0	0
13	15-Apr-13	1	4	R4	56	9:34	5	0.4	1
14	15-Apr-13	1	4	R6	55	11:05	5	2.9	3
14	15-Apr-13	1	4	R6	55	11:11	1	8.7	12
14	15-Apr-13	1	4	R6	55	11:16	3	7.2	19
14	15-Apr-13	1	4	R6	57	11:21	4	13.4	13
14	15-Apr-13	1	4	R6	57	11:26	6	27.1	33
14	15-Apr-13	1	4	R6	56	11:31	2	22.5	34
15	15-Apr-13	1	5	R3	62	13:10	2	5.4	33
15	15-Apr-13	1	5	R3	62	13:15	6	3.6	47
15	15-Apr-13	1	5	R3	61	13:21	4	10.6	68
15	15-Apr-13	1	5	R3	59	13:26	3	7.4	49
15	15-Apr-13	1	5	R3	59	13:31	1	5.2	52
15	15-Apr-13	1	5	R3	62	13:36	5	3.4	20
16	16-Apr-13	1	5	R2	66	15:15	5	3.1	22
16	16-Apr-13	1	5	R2	65	15:20	1	4.8	30
16	16-Apr-13	1	5	R2	65	15:25	3	6.5	37

Set	Date	Phase	Stratum	Site	Depth (m)	Time set	Pot	Catch of blue cod (kg)	Number
16	16-Apr-13	1	5	R2	63	15:30	4	4.2	27
16	16-Apr-13	1	5	R2	65	15:35	6	9	15
16	16-Apr-13	1	5	R2	64	15:40	2	8.5	40
17	18-Apr-13	1	6	R1	63	12:00	2	27.1	19
17	18-Apr-13	1	6	R1	62	12:05	6	18.8	15
17	18-Apr-13	1	6	R1	59	12:10	4	11.8	7
17	18-Apr-13	1	6	R1	60	12:15	3	6.2	5
17	18-Apr-13	1	6	R1	61	12:20	1	4.2	3
17	18-Apr-13	1	6	R1	61	12:26	5	10	9
18	18-Apr-13	1	6	R6	71	14:20	5	8.8	11
18	18-Apr-13	1	6	R6	72	14:25	1	3.4	13
18	18-Apr-13	1	6	R6	70	14:30	3	3.2	7
18	18-Apr-13	1	6	R6	70	14:35	4	3.3	23
18	18-Apr-13	1	6	R6	72	14:40	6	2.2	11
18	18-Apr-13	1	6	R6	70	14:45	2	8.3	6
19	1-May-13	1	5	R4	61	13:50	4	6.7	20
19	1-May-13	1	5	R4	61	13:55	3	6.2	20
19	1-May-13	1	5	R4	62	14:00	1	25.5	28
19	1-May-13	1	5	R4	60	14:05	5	5.4	5
19	1-May-13	1	5	R4	61	14:10	6	20.2	21
19	1-May-13	1	5	R4	61	14:15	2	28.8	32
20	2-May-13	1	6	R3	72	7:55	2	24.7	24
20	2-May-13	1	6	R3	72	8:00	6	43.2	41
20	2-May-13	1	6	R3	72	8:05	5	42.2	39
20	2-May-13	1	6	R3	70	8:10	1	20.8	31
20	2-May-13	1	6	R3	71	8:15	3	22	36
20	2-May-13	1	6	R3	71	8:20	4	12.6	21
21	2-May-13	1	5	R6	67	10:06	4	15.1	79
21	2-May-13	1	5	R6	68	10:11	3	14	90
21	2-May-13	1	5	R6	69	10:16	1	8.6	34
21	2-May-13	1	5	R6	69	10:22	5	12.9	76
21	2-May-13	1	5	R6	68	10:27	6	11.9	65
21	2-May-13	1	5	R6	67	10:33	2	11.6	57
22	2-May-13	1	5	R5	60	15:52	2	2	10
22	2-May-13	1	5	R5	61	15:56	6	1.4	8
22	2-May-13	1	5	R5	59	15:59	5	0	0
22	2-May-13	1	5	R5	59	16:03	1	1.2	1
22	2-May-13	1	5	R5	60	16:06	3	0.3	2
22	2-May-13	1	5	R5	60	16:09	4	1	4
23	8-May-13	1	4	R2	59	12:35	4	2.4	9
23	8-May-13	1	4	R2	57	12:40	3	1.8	11
23	8-May-13	1	4	R2	58	12:45	1	2	8
23	8-May-13	1	4	R2	58	12:50	5	2	12
23	8-May-13	1	4	R2	57	12:55	6	1.4	8
23	8-May-13	1	4	R2	57	13:00	2	2.2	2
24	8-May-13	1	4	R1	59	14:25	2	21.4	43
24	8-May-13	1	4	R1	57	14:30	6	11.1	25
24	8-May-13	1	4	R1	57	14:35	5	9.2	31

Set	Date	Phase	Stratum	Site	Depth (m)	Time set	Pot	Catch of blue cod (kg)	Number
24	8-May-13	1	4	R1	57	14:40	1	11.2	37
24	8-May-13	1	4	R1	57	14:45	3	9.3	41
24	8-May-13	1	4	R1	57	14:50	4	5.3	19
25	9-May-13	1	3	R1	125	8:35	4	0.9	1
25	9-May-13	1	3	R1	125	8:45	3	1.7	1
25	9-May-13	1	3	R1	126	8:53	1	0	0
25	9-May-13	1	3	R1	126	9:03	5	3.3	2
25	9-May-13	1	3	R1	125	9:12	6	1.7	2
25	9-May-13	1	3	R1	126	9:20	2	0	0
26	9-May-13	1	3	R2	115	10:36	2	14.4	10
26	9-May-13	1	3	R2	112	10:44	6	23.3	18
26	9-May-13	1	3	R2	112	10:52	5	9.5	10
26	9-May-13	1	3	R2	111	10:59	1	15	14
26	9-May-13	1	3	R2	112	11:07	3	12.1	10
26	9-May-13	1	3	R2	113	11:15	4	21.5	15
27	9-May-13	1	3	R3	106	12:40	4	0.7	4
27	9-May-13	1	3	R3	104	12:50	3	0.6	5
27	9-May-13	1	3	R3	104	12:58	1	0.8	6
27	9-May-13	1	3	R3	104	13:05	5	0.6	4
27	9-May-13	1	3	R3	104	13:13	6	1	6
27	9-May-13	1	3	R3	106	13:20	2	0.6	4
28	13-May-13	1	3	R4	129	9:15	2	0	0
28	13-May-13	1	3	R4	129	9:23	4	0	0
28	13-May-13	1	3	R4	130	9:31	3	5.1	11
28	13-May-13	1	3	R4	132	9:40	5	1.6	2
28	13-May-13	1	3	R4	132	9:48	6	0.5	1
28	13-May-13	1	3	R4	134	9:57	1	1.9	1
29	13-May-13	1	3	R5	151	11:05	1	15.7	15
29	13-May-13	1	3	R5	149	11:12	6	10.4	12
29	13-May-13	1	3	R5	147	11:20	5	6.5	10
29	13-May-13	1	3	R5	147	11:28	3	8.7	11
29	13-May-13	1	3	R5	150	11:36	4	13.6	15
29	13-May-13	1	3	R5	151	11:44	2	19.8	19
30	13-May-13	1	3	R6	105	12:52	2	0	0
30	13-May-13	1	3	R6	106	13:00	4	1	6
30	13-May-13	1	3	R6	107	13:07	3	0	0
30	13-May-13	1	3	R6	105	13:13	5	0.5	3
30	13-May-13	1	3	R6	104	13:20	6	0.1	1
30	13-May-13	1	3	R6	105	13:27	1	0.1	1
31	14-May-13	1	1	R6	25	8:40	2	0	0
31	14-May-13	1	1	R6	27	8:46	4	0	0
31	14-May-13	1	1	R6	23	8:52	5	0	0
31	14-May-13	1	1	R6	19	8:58	1	0	0
31	14-May-13	1	1	R6	17	9:05	3	0	0
31	14-May-13	1	1	R6	20	9:10	6	0	0
32	14-May-13	1	1	R5	27	10:37	6	0	0
32	14-May-13	1	1	R5	27	10:42	3	0	0
32	14-May-13	1	1	R5	30	10:46	1	0	0

Set	Date	Phase	Stratum	Site	Depth (m)	Time set	Pot	Catch of blue cod (kg)	Number
32	14-May-13	1	1	R5	35	10:50	5	0	0
32	14-May-13	1	1	R5	40	10:55	4	0	0
32	14-May-13	1	1	R5	37	11:00	2	0	0
33	14-May-13	1	1	R4	35	12:55	2	0	0
33	14-May-13	1	1	R4	32	13:00	4	0	0
33	14-May-13	1	1	R4	33	13:05	5	0	0
33	14-May-13	1	1	R4	37	13:10	1	0	0
33	14-May-13	1	1	R4	38	13:14	3	0	0
33	14-May-13	1	1	R4	39	13:18	6	0	0
34	15-May-13	1	1	R3	32	8:20	6	0	0
34	15-May-13	1	1	R3	31	8:25	3	0	0
34	15-May-13	1	1	R3	30	8:30	1	0	0
34	15-May-13	1	1	R3	30	8:35	5	0	0
34	15-May-13	1	1	R3	30	8:40	4	0	0
34	15-May-13	1	1	R3	31	8:45	2	0	0
35	15-May-13	1	1	R2	14	10:13	2	0	0
35	15-May-13	1	1	R2	14	10:18	4	0	0
35	15-May-13	1	1	R2	15	10:23	5	0	0
35	15-May-13	1	1	R2	15	10:30	1	0	0
35	15-May-13	1	1	R2	16	10:35	3	0	0
35	15-May-13	1	1	R2	15	10:40	6	0	0
36	15-May-13	1	1	R1	25	12:17	6	0	0
36	15-May-13	1	1	R1	23	12:22	3	0	0
36	15-May-13	1	1	R1	22	12:26	1	0	0
36	15-May-13	1	1	R1	24	12:30	5	0	0
36	15-May-13	1	1	R1	25	12:34	4	0	0
36	15-May-13	1	1	R1	26	13:38	2	0	0
37	16-May-13	2	2	R7	26	9:40	2	0	0
37	16-May-13	2	2	R7	25	9:45	4	0	0
37	16-May-13	2	2	R7	25	9:50	5	0	0
37	16-May-13	2	2	R7	27	9:54	1	0	0
37	16-May-13	2	2	R7	28	9:58	3	0	0
37	16-May-13	2	2	R7	29	10:02	6	0	0
38	16-May-13	2	2	R8	29	11:10	6	1	5
38	16-May-13	2	2	R8	29	11:13	3	0.3	1
38	16-May-13	2	2	R8	30	11:16	1	1.7	1
38	16-May-13	2	2	R8	29	11:19	5	41.9	53
38	16-May-13	2	2	R8	31	11:22	4	0.3	1
38	16-May-13	2	2	R8	31	11:25	2	1.5	6
39	16-May-13	2	1	R7	35	14:16	2	0	0
39	16-May-13	2	1	R7	37	14:20	4	4.4	9
39	16-May-13	2	1	R7	37	14:24	5	0	0
39	16-May-13	2	1	R7	41	14:28	1	0	0
39	16-May-13	2	1	R7	40	14:32	3	0.8	1
39	16-May-13	2	1	R7	32	14:36	6	32.8	46
40	17-May-13	2	1	R8	29	9:24	6	0	0
40	17-May-13	2	1	R8	30	9:30	3	0	0
40	17-May-13	2	1	R8	30	9:35	1	0	0

Set	Date	Phase	Stratum	Site	Depth (m)	Time set	Pot	Catch of blue cod (kg)	Catch of blue cod Number
40	17-May-13	2	1	R8	29	9:40	5	0	0
40	17-May-13	2	1	R8	28	9:45	4	0	0
40	17-May-13	2	1	R8	28	9:50	2	0	0

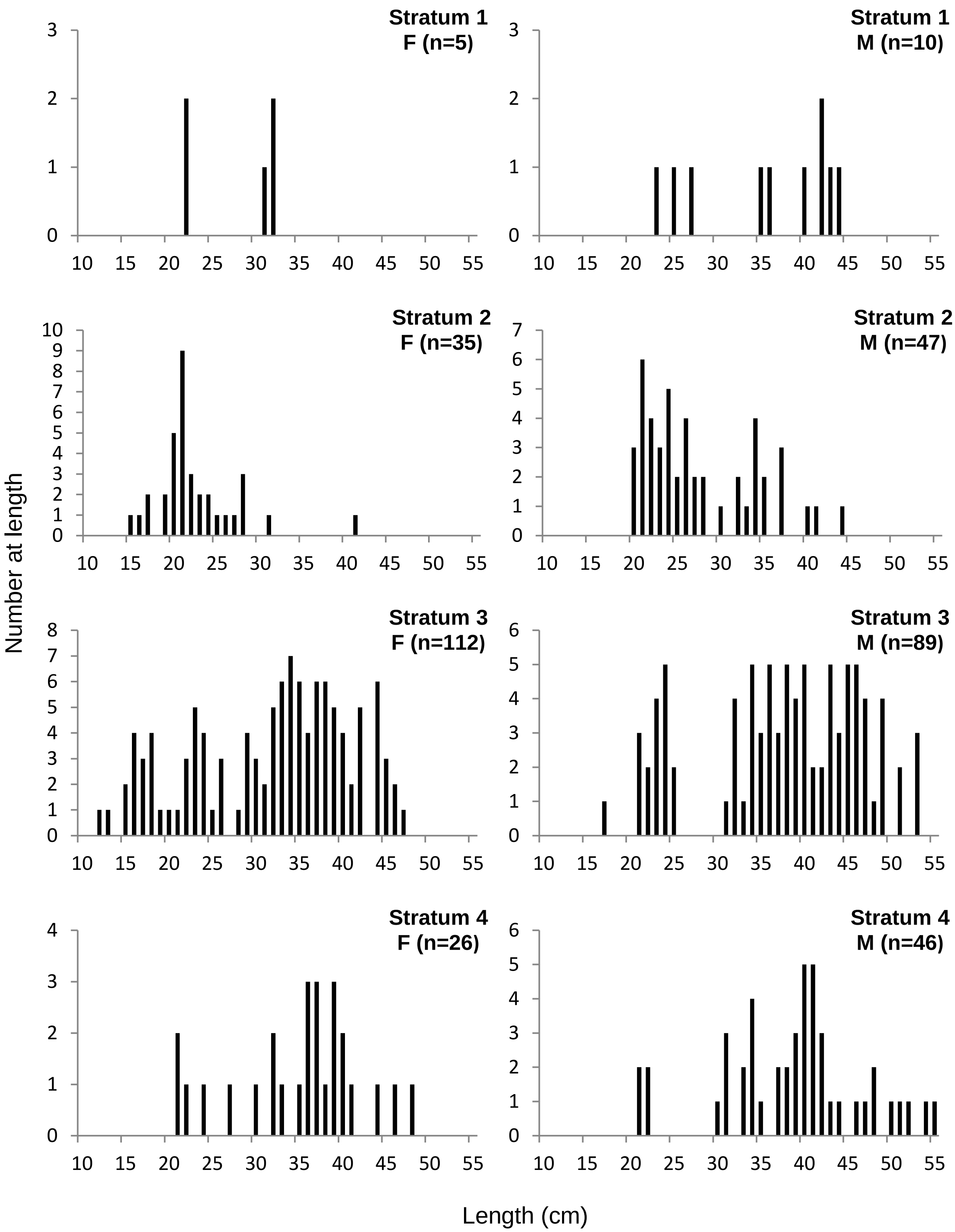
Appendix 3: Summary of the south Otago 2013 survey oceanographic environmental station data recorded in the format of the trawl data base.
Depths are measured in metres, directions in compass degrees (999 = nil), wind force in the Beaufort scale, temperatures in degrees celcius, air pressure in millibars, cloud cover in oktas, sea condition in the Douglas scale, sea colour in a categorical scale from 1 (deep blue) to 8 (yellow green), swell height in metres, bottom type in a categorical scale from 1 (mud or ooze) to 13 (sponge beds), bottom contour in a categorical scale from 1 (smooth/flat) to 5 (very rugged), and wind speed in metres per second.

Set	ADCP Depth	Wind Direction	Wind Force	Air Temp	Air Pressure	Cloud Cover	Sea Condition	Sea Colour	Swell Height	Swell Direction	Bottom Type	Bottom Contour	Surface Temp	Bottom Temp	Wind Speed	Secchi Depth
1	22	260	5	12.7	1020	6	3	4	0.5	130	3	1	14.5		8.1	5.0
2	31	200	4	12.6	1020	7	3	4	0.5	130	3	1	14.5		6.4	5.5
3	26	220	4	13.4	1022	3	3	8	1	180	3	1	14.1		7.0	5.1
4	17	180	3	15.0	1023	3	3	8	1	170	3	1	14.2		4.5	4.0
5	22	050	2	15.4	1024	2	2	5	0.5	180	3	1	14.2		2.9	5.5
6	22	030	3	15.4	1020	7	2	7	0.5	030	3	1	14.1		4.2	5.5
7	40	270	4	13.8	1015	7	3	4	1	180	3	1	14.1		6.7	5.5
8	46	250	4	15.4	1015	8	3	4	1	200	3	2	14.1		7.9	5.5
9	57	000	2	15.2	1018	2	2	6	2	130	4	2	14.1		2.7	10.5
10	60	999	0	18.5	1010	4	2	7	1	330	7	2	14.2		0.0	8.0
11	59	270	6	12.5	1015	7	4	2	2	220	7	2	14.0		12.9	9.5
12	30	230	6	14.4	1015	6	4	2	2	220	3	1	14.0		11.1	8.5
13	56	240	2	15.6	1015	7	2	6	0.5	030	4	2	14.1		2.0	9.8
14	56	350	2	18.0	1013	7	2	6	0.5	030	6	2	14.2		2.5	10.0
15	61	310	2	18.0	1010	6	2	6	1	020	8	2	14.3		1.8	10.6
16	64	090	4	15.8	1010	8	3	6	1.5	050	8	2	14.3		6.1	10.4
17	62	210	4	15.3	1006	5	4	5	1.5	200	4	2	14.0		6.0	11.4
18	71	210	3	15.9	1007	2	4	5	2	150	7	2	14.1		4.4	9.4
19	60	050	4	16.8	1017	3	3	7	2	150	7	2	14.1		6.0	10.0
20	72	000	1	9.7	1009	7	3	7	2	150	6	2	14.0		1.5	10.0
21	68	160	1	11.5	1018	8	3	7	2	150	8	1	14.0		1.2	10.0
22	61	280	2	13.1	1008	8	2	7	1.5	180	6	1	14.0		2.0	10.5
23	59	270	4	15.4	1022	5	4	7	2.5	190	6	2	14.0		7.0	10.0
24	58	240	4	14.1	1021	6	4	7	2.5	190	5	2	13.9		6.1	10.0
25		330	5	10.3	1014	1	4	4	2.5	150	5	2	13.8		9.3	14.0
26		330	5	12.6	1010	3	4	4	2.5	150	8	2	13.8		10.2	14.0
27		010	6	12.5	1006	7	5	4	3	150	5	2	13.8		12.3	13.5
28		350	3	13.4	1024	8	4	5	2	150	5	3	12.1		4.1	14.0
29		010	3	14.5	1024	4	4	5	2	150	9	2	13.1		5.4	14.0

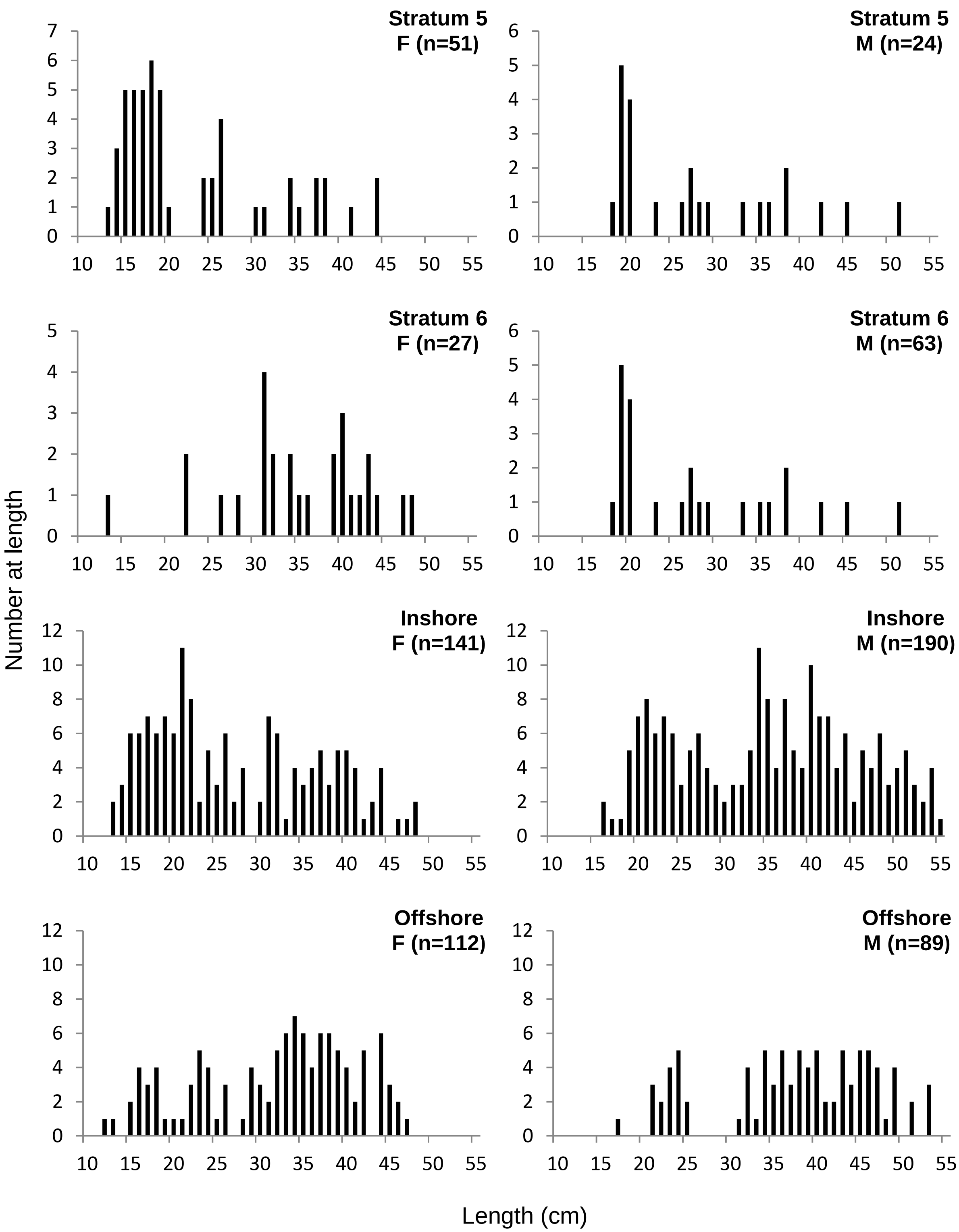
Appendix 3– *continued*

Set	Average Depth	Wind Direction	Wind Force	Air Temp	Air Pressure	Cloud Cover	Sea Condition	Sea Colour	Swell Height	Swell Direction	Bottom Type	Bottom Contour	Surface Temp	Bottom Temp	Wind Speed	Secchi Depth
30		270	4	15.1	1024	3	4	5	2	150	6	2	13.1		6.6	14.0
31	22	260	3	15.7	1015	6	3	8	0.75	200	3	1	12.0		3.6	3.1
32	31	180	1	22.2	1014	4	3	7	0.5	130	7	3	12.0		1.5	4.0
33	35	330	3	23.0	1014	6	3	7	0.5	240	6	1	12.0		4.4	3.8
34	30	260	2	15.4	1014	8	3	8	1.5	160	4	1	12.0		3.3	3.2
35	15	130	1	14.7	1013	8	3	8	1.5	130	3	1	12.0		1.5	3.1
36	24	060	2	17.3	1014	8	2	8	1	140	3	1	12.0		1.8	6.1
37	26	300	2	16.1	1013	3	3	7	2.5	130	3	1	11.8		3.1	3.5
38	29	270	2	17.1	1013	4	3	7	2.5	130	7	2	11.7		2.3	3.4
39	36	300	3	18.4	1013	7	2	7	2.5	160	7	4	11.9		5.2	6.2
40	29	225	1	10.0	1018	6	2	6	1	050	6	1	12.0		1.4	4.2

Appendix 4: Unscaled length frequency distributions of blue cod for each stratum from which separate sets of otoliths were used for age length keys of both inshore (i.e, all strata except stratum 3) and offshore (i.e., stratum 3 only) areas of south Otago 2013.



Appendix 4– *continued*



Appendix 5: Between-reader comparisons (using first independent readings only) for otolith data collected from inshore strata (excluding stratum 3) of south Otago 2013.

Reader two	Age class (reader one)														
difference	2	3	4	5	6	7	8	9	10	11	12	13	14	15	≥16	Total
-4												1				1
-3								1					1			3
-2			2	1	1	1	1			1	1	1		1	1	11
-1	3	1	7	3	3	2	3	1	1	2	2	3	4	2	1	39
0	12	34	29	12	6	10	10	8	11	14	7	7	3	4	2	177
1		2	5	4	3		2	1	3	4	1	2	2	4	10	41
2									1	2			2	2	8	14
3												1			7	5
4															4	2
5															2	5
6															5	3
7															3	2
8															2	1
9															1	1
Total	15	37	43	20	13	13	16	11	16	23	11	15	15	13	47	305
% agreement	80	92	67	60	46	77	63	73	69	61	64	47	80	31	21	58

Appendix 6: Independent reader comparisons with agreed age from otolith data collected from inshore strata (excluding stratum 3) of south Otago 2013.

Reader one	Agreed age class														
difference	2	3	4	5	6	7	8	9	10	11	12	13	14	15	≥16	Total
-6															2	2
-5																
-4															1	1
-3															7	7
-2									1	2			1		7	11
-1		2	5	3	3		1	1	3	4	1	2	4	5	13	47
0	12	35	31	17	9	12	11	8	13	14	8	9	4	5	14	202
1	2		2	2	3	2	3	1	1	2	2	2	4	1		27
2						1			1		1			2	2	7
3													1			1
Total	1	6	28	36	21	26	24	31	18	12	8	8	2	13	46	305
% agreement	100	100	96	97	81	77	63	58	72	50	75	88	100	38	30	66

Reader two	Agreed age class														
difference	2	3	4	5	6	7	8	9	10	11	12	13	14	15	≥16	Total
-10									1							1
-2							1		1			1		1		4
-1		1	1	7	4	1			1				2	1	4	22
0	14	36	36	15	11	13	14	10	16	22	11	12	10	10	26	256
1			1			1							2	1	5	10
2											1				3	4
3															5	5
4															1	1
5															1	1
6															1	1
Total	14	37	38	22	15	15	15	10	19	22	12	13	14	13	46	305
% agreement	100	97	95	68	73	87	93	100	84	100	92	92	71	77	57	84

Appendix 7: Between-reader comparisons (using first independent readings only) for otolith data collected from the offshore stratum (3) of south Otago 2013.

Reader two	Age class (reader one)														
difference	1	2	3	4	5	6	7	8	9	10	11	12	13	14	≥15	Total
-2										1	1				1	1
-1			2	2	1		2	2	1	4	2			1	4	1
0	1	3	11	9	2	3	9	9	9	7	3	3		6	26	4
1			9	9		1	2	4	1	7	4	3	1	1	23	10
2							1	1	1	2	3	2	1	2	6	13
3										2	2	2	1		8	33
4												1		1	6	122
5												1			7	29
6														1	7	7
8															8	2
9															9	
Total	1	3	22	20	3	4	14	16	12	23	15	12	3	12	105	200
% agreement	100	100	50	45	67	75	64	56	75	30	20	25	0	50	25	39

Appendix 8: Independent reader comparisons with agreed age from otolith data collected from the offshore stratum (3) of south Otago 2013.

Reader one	Agreed age class															
difference	1	2	3	4	5	6	7	8	9	10	11	12	13	14	≥15	Total
-5															1	1
-3															1	1
-2													1		1	2
-1				1	1	1		2	1	2	2	1	1		2	14
0	1	3	21	17	2	4	12	15	10	21	13	8	3	10	29	169
1			2								1		1		1	5
2										2		1			2	5
3															1	1
4															2	2
Total	1	3	23	18	3	5	12	17	11	25	16	10	6	10	40	200
% agreement	100	100	91	94	67	80	100	88	91	84	81	80	50	100	73	85

Reader two	Agreed age class															
difference	1	2	3	4	5	6	7	8	9	10	11	12	13	14	≥15	Total
-4														1	1	3
-3															4	8
-2								1			1	1	1		4	12
-1								3	3	1	1	2	2	1		13
0	1	4	8	4	8	6	7	2	4	3	2	2	1	4	4	64
1			1	1	1								1		1	6
Total	1	4	9	5	9	6	7	6	7	4	4	5	5	6	14	106
% agreement	100	100	89	80	89	100	100	33	57	75	50	40	20	67	29	60

Appendix 9: The proportion of fish at age and length and the total number at length and at age for male blue cod sampled from the 2013 south Otago survey inshore strata (age -length-key, ALK).

	Age																										
Length	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	21	22	23	24	25	26	28	29	32	Total
16	0.5	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
17	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
18	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
19	0	0.6	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
20	0	0.71	0.29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
21	0	0.43	0.43	0.14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
22	0	0.33	0.67	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
23	0	0	0.71	0.29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
24	0	0	0.67	0.33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
25	0	0	0.5	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
26	0	0	0	0.6	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
27	0	0	0.17	0.17	0.67	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
28	0	0	0	0.25	0.25	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
29	0	0	0	0	0	0.67	0.33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
30	0	0	0	0	0	0.5	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
31	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
32	0	0	0	0	0	0.67	0	0.33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
33	0	0	0	0	0	0	0.6	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
34	0	0	0	0	0.11	0.11	0.11	0.44	0.11	0.11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
35	0	0	0	0	0	0.14	0.43	0	0.29	0.14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
36	0	0	0	0	0	0	0	0	0.67	0.33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
37	0	0	0	0	0	0	0.12	0	0.38	0.25	0.12	0.12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
38	0	0	0	0	0	0	0	0	0.67	0.33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
39	0	0	0	0	0	0	0	0	0	0.33	0	0.33	0.33	0	0	0	0	0	0	0	0	0	0	0	0	0	3
40	0	0	0	0	0	0	0	0	0	0.33	0.22	0.44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
41	0	0	0	0	0	0	0	0	0	0.29	0.29	0.14	0.29	0	0	0	0	0	0	0	0	0	0	0	0	0	7
42	0	0	0	0	0	0	0	0	0	0.5	0.17	0	0.17	0.17	0	0	0	0	0	0	0	0	0	0	0	0	6
43	0	0	0	0	0	0	0	0	0	0.5	0	0.25	0.25	0	0	0	0	0	0	0	0	0	0	0	0	0	4
44	0	0	0	0	0	0	0	0	0	0.17	0.17	0	0.33	0.17	0.17	0	0	0	0	0	0	0	0	0	0	0	6
45	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	2
46	0	0	0	0	0	0	0	0	0	0	0	0	0	0.75	0	0	0	0	0	0.25	0	0	0	0	0	0	4

47	0	0	0	0	0	0	0	0	0	0	0	0	0	0.33	0.33	0	0.33	0	0	0	0	0	0	0	0	0	3
48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.17	0	0.33	0	0.5	0	0	0	0	0	0	0	6
49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.33	0.33	0	0	0	0.33	0	0	0	0	0	3
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0.25	0.25	0	0	0	4
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0	0.2	0.2	0.2	0	0.2	0	5
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.33	0.33	0	0	0.33	0	0	0	0	0	3
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0.5	2
54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0.25	0.25	0	0	4
55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
Total	2	15	22	11	8	11	10	6	11	18	8	8	7	7	3	1	5	1	4	3	3	5	3	1	2	1	176

Appendix 10: The proportion of fish at age and length and the total number at length and at age for female blue cod sampled from the 2013 south Otago survey inshore strata (age-length key, ALK).

	Age																								
Length	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Total
13	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
14	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
15	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
16	0.25	0.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
17	0.17	0.83	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
18	0	0.83	0.17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
19	0	0.8	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
20	0	0.4	0.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
21	0	0.22	0.67	0.11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
22	0	0.12	0.62	0.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
23	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
24	0	0	0	0.67	0.33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
25	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
26	0	0	0	0.5	0.33	0.17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
27	0	0	0	0	0.5	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
28	0	0	0	0	0.5	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
30	0	0	0	0	0	0	0.5	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
31	0	0	0	0	0	0	0.43	0.14	0.43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
32	0	0	0	0	0	0.17	0	0.33	0.17	0.33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
33	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
34	0	0	0	0	0	0	0	0	0.25	0.25	0.25	0	0	0.25	0	0	0	0	0	0	0	0	0	0	4
35	0	0	0	0	0	0	0	0	0	0.5	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	2
36	0	0	0	0	0	0	0	0.33	0	0	0.67	0	0	0	0	0	0	0	0	0	0	0	0	0	3
37	0	0	0	0	0	0	0	0	0.2	0	0	0.2	0.6	0	0	0	0	0	0	0	0	0	0	0	5
38	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0.5	0	0	0	0	0	0	0	0	0	0	2
39	0	0	0	0	0	0	0	0	0	0	0	0.2	0.2	0.4	0	0.2	0	0	0	0	0	0	0	0	5
40	0	0	0	0	0	0	0	0	0	0	0	0.2	0	0.4	0	0	0.2	0	0	0	0.2	0	0	0	5
41	0	0	0	0	0	0	0	0	0	0	0	0.5	0.25	0	0.25	0	0	0	0	0	0	0	0	0	4
42	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0.5	0	0	2
44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0.5	0	0	0	0	0	0	4
46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
47	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2
Total	12	22	16	11	7	4	5	4	8	4	4	5	7	6	1	3	1	2	0	2	1	1	1	2	129

Appendix 11: The proportion of fish at age and length and the total number at length and at age for male blue cod sampled from the 2013 south Otago survey offshore stratum (age -length-key, ALK).

	Age																											
Length	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	Total
17	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
21	0.67	0.33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
22	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
23	0.25	0.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
24	0	0.8	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
25	0	0.5	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
31	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
32	0	0	0	0.25	0.5	0.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
33	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
34	0	0	0	0.2	0.4	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
35	0	0	0	0	0.67	0	0.33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
36	0	0	0	0	0.2	0.6	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
37	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
38	0	0	0	0	0	0.2	0	0.4	0.2	0	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
39	0	0	0	0	0	0	0	0.5	0	0.25	0.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
40	0	0	0	0	0	0	0.2	0.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
41	0	0	0	0	0	0	0	0.5	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
42	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
43	0	0	0	0	0	0	0	0	0.6	0	0	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
44	0	0	0	0	0	0	0.33	0.33	0	0	0	0	0	0	0	0.33	0	0	0	0	0	0	0	0	0	0	0	3
45	0	0	0	0	0	0	0	0	0	0.2	0.2	0.4	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
46	0	0	0	0	0	0	0	0.2	0	0	0	0.2	0.2	0	0	0.2	0	0.2	0	0	0	0	0	0	0	0	0	5
47	0	0	0	0	0	0	0	0	0	0	0	0	0	0.25	0	0.25	0.25	0.25	0	0	0	0	0	0	0	0	0	4
48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.25	0	0	0	0.25	0.5	0	0	0	0	4
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0.5	2
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.33	0.33	0	0.33	0	3
Total	6	9	2	3	7	8	4	11	7	4	3	5	3	1	1	3	1	3	0	0	0	2	3	1	0	1	1	89

Appendix 12: The proportion of fish at age and length and the total number at length and at age for female blue cod sampled from the 2013 south Otago survey offshore stratum (age-length key, ALK).

	Age																												
Length	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	Total
12	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
13	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
15	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
16	0	0.5	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
17	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
18	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
19	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
20	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
21	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
22	0	0	0.33	0.67	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
23	0	0	0.2	0.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
24	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
25	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
26	0	0	0	0	0.33	0.33	0.33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
28	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
29	0	0	0	0	0	0.25	0.5	0.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
30	0	0	0	0	0	0	0.33	0.67	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
31	0	0	0	0	0	0	0	0.5	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
32	0	0	0	0	0	0	0	0.2	0.2	0.4	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
33	0	0	0	0	0	0	0	0.17	0	0.33	0.33	0.17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
34	0	0	0	0	0	0	0	0.29	0.29	0.43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
35	0	0	0	0	0	0	0	0.17	0.33	0.17	0.17	0.17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
36	0	0	0	0	0	0	0	0	0	0.75	0	0.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
37	0	0	0	0	0	0	0	0	0.17	0.17	0.5	0	0.17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
38	0	0	0	0	0	0	0	0	0	0.17	0.17	0.17	0	0.17	0	0.17	0	0.17	0	0	0	0	0	0	0	0	0	0	6
39	0	0	0	0	0	0	0	0	0	0	0	0.4	0.4	0	0	0	0	0	0.2	0	0	0	0	0	0	0	0	0	5
40	0	0	0	0	0	0	0	0	0	0.25	0.25	0	0	0.25	0	0	0	0.25	0	0	0	0	0	0	0	0	0	0	4
41	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	2
42	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0.2	0.4	0	0	0.2	0	0	0	0	0	0	0	0	0	5
44	0	0	0	0	0	0	0	0	0	0	0	0	0	0.17	0.17	0	0	0	0	0.17	0.17	0	0.17	0	0	0	0	0.17	6
45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.33	0	0	0	0.33	0	0	0	0.33	0	0	0	0	3
46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0.5	0	0	0	0	0	0	0	2
47	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
Total	1	3	17	9	1	2	5	9	7	14	9	6	3	5	3	4	0	2	3	2	2	0	1	1	0	1	0	1	111

Appendix 13: Mean age-at-length for the 2013 south Otago survey inshore strata.

	Males		Females		All fish	
Length (cm)	N	Mean age	N	Mean age	N	Mean age
13	0	0.0	2	2.0	2	2.0
14	0	0.0	3	2.0	3	2.0
15	0	0.0	5	2.0	5	2.0
16	2	2.5	4	2.8	6	2.7
17	1	2.0	6	2.8	7	2.7
18	1	3.0	6	3.2	7	3.1
19	5	3.4	5	3.2	10	3.3
20	7	3.3	5	3.6	12	3.4
21	7	3.7	9	3.9	16	3.8
22	6	3.7	8	4.1	14	3.9
23	7	4.3	1	6.0	8	4.5
24	6	4.3	3	5.3	9	4.7
25	2	4.5	3	5.0	5	4.8
26	5	5.4	6	5.7	11	5.6
27	6	5.5	2	7.0	8	5.9
28	4	6.3	4	6.5	8	6.4
29	3	7.3	0	0.0	3	7.3
30	2	7.5	2	9.0	4	8.3
31	2	7.0	7	9.0	9	8.6
32	3	7.7	6	9.5	9	8.9
33	5	8.6	1	10.0	6	8.8
34	9	8.7	4	12.0	13	9.7
35	7	8.9	2	12.5	9	9.7
36	3	10.3	3	11.0	6	10.7
37	8	10.6	5	13.0	13	11.5
38	3	10.3	2	13.5	5	11.6
39	3	12.7	5	14.8	8	14.0
40	9	12.1	5	16.6	14	13.7
41	7	12.4	4	14.0	11	13.0
42	6	12.3	1	14.0	7	12.6
43	4	12.2	2	22.0	6	15.5
44	6	13.7	4	18.0	10	15.4
45	2	13.5	0	0.0	2	13.5
46	4	17.0	1	21.0	5	17.8
47	3	16.3	1	24.0	4	18.2
48	6	19.7	2	25.0	8	21.0
49	3	19.7	0	0.0	3	19.7
50	4	24.2	0	0.0	4	24.2
51	5	25.2	0	0.0	5	25.2
52	3	21.0	0	0.0	3	21.0
53	2	30.5	0	0.0	2	30.5
54	4	26.0	0	0.0	4	26.0
55	1	25.0	0	0.0	1	25.0
Total	176	10.7	129	8.2	305	9.7

Appendix 14: Mean age-at-length for the 2013 south Otago survey offshore stratum.

	Males		Females		All fish	
Length (cm)	N	Mean age	N	Mean age	N	Mean age
12	0	0.0	1	1.0	1	1.0
13	0	0.0	1	2.0	1	2.0
15	0	0.0	2	3.0	2	3.0
16	0	0.0	4	2.5	4	2.5
17	1	3.0	3	3.0	4	3.0
18	0	0.0	4	3.0	4	3.0
19	0	0.0	1	3.0	1	3.0
20	0	0.0	1	3.0	1	3.0
21	3	3.3	1	3.0	4	3.3
22	2	3.0	3	3.7	5	3.4
23	4	3.8	5	3.8	9	3.8
24	5	4.2	3	4.0	8	4.1
25	2	4.5	1	3.0	3	4.0
26	0	0.0	3	6.0	3	6.0
28	0	0.0	1	7.0	1	7.0
29	0	0.0	4	7.0	4	7.0
30	0	0.0	3	7.7	3	7.7
31	1	6.0	2	8.5	3	7.7
32	4	7.0	5	9.6	9	8.4
33	1	8.0	6	10.3	7	10.0
34	5	7.2	7	9.1	12	8.3
35	3	7.7	6	9.8	9	9.1
36	5	8.0	4	10.5	9	9.1
37	3	11.0	6	10.8	9	10.9
38	5	10.4	6	13.5	11	12.1
39	4	11.2	5	13.8	9	12.7
40	5	9.8	4	13.2	9	11.3
41	2	12.0	2	14.5	4	13.2
42	2	12.0	5	16.0	7	14.9
43	5	12.4	0	0.0	5	12.4
44	3	12.3	6	20.2	9	17.6
45	5	13.6	3	20.0	8	16.0
46	5	15.4	2	20.0	7	16.7
47	4	18.2	1	26.0	5	19.8
48	1	17.0	0	0.0	1	17.0
49	4	23.5	0	0.0	4	23.5
51	2	26.5	0	0.0	2	26.5
53	3	26.3	0	0.0	3	26.3
Total	89	11.2	111	9.8	200	10.4

Appendix 15: Parameter values used in the 2013 south Otago inshore strata SPR analyses.

	Males				Females			
Age	Length (cm)	Weight (kg)	Selectivity	Maturity	Length (cm)	Weight (kg)	Selectivity	Maturity
1	11.8	0.022	0	0	11.7	0.022	0	0
2	15.7	0.056	0	0	15.1	0.049	0	0
3	19.3	0.107	0	0	18.2	0.089	0	0
4	22.5	0.175	0	0.1	21.0	0.140	0	0.1
5	25.5	0.260	0	0.4	23.5	0.203	0	0.4
6	28.2	0.360	0	0.7	25.9	0.274	0	0.7
7	30.7	0.470	1	1	28.0	0.353	0	1
8	33.0	0.590	1	1	30.0	0.437	0	1
9	35.0	0.716	1	1	31.7	0.525	1	1
10	36.9	0.847	1	1	33.4	0.615	1	1
11	38.6	0.979	1	1	34.8	0.706	1	1
12	40.2	1.112	1	1	36.2	0.797	1	1
13	41.7	1.244	1	1	37.4	0.886	1	1
14	43.0	1.374	1	1	38.5	0.973	1	1
15	44.2	1.500	1	1	39.6	1.058	1	1
16	45.3	1.621	1	1	40.5	1.139	1	1
17	46.3	1.738	1	1	41.3	1.217	1	1
18	47.2	1.850	1	1	42.1	1.291	1	1
19	48.0	1.956	1	1	42.8	1.361	1	1
20	48.8	2.057	1	1	43.5	1.428	1	1
21	49.5	2.152	1	1	44.0	1.490	1	1
22	50.1	2.241	1	1	44.6	1.548	1	1
23	50.7	2.325	1	1	45.1	1.603	1	1
24	51.2	2.403	1	1	45.5	1.654	1	1
25	51.7	2.476	1	1	45.9	1.702	1	1
26	52.1	2.544	1	1	46.3	1.746	1	1
27	52.5	2.608	1	1	46.6	1.787	1	1
28	52.9	2.666	1	1	46.9	1.824	1	1
29	53.2	2.721	1	1	47.2	1.859	1	1
30	53.5	2.771	1	1	47.5	1.892	1	1
31	53.8	2.818	1	1	47.7	1.922	1	1
32	54.1	2.860	1	1	47.9	1.949	1	1
33	54.3	2.900	1	1	48.1	1.974	1	1
34	54.5	2.937	1	1	48.3	1.998	1	1
35	54.7	2.970	1	1	48.4	2.019	1	1
36	54.9	3.001	1	1	48.6	2.039	1	1
37	55.1	3.029	1	1	48.7	2.057	1	1
38	55.2	3.056	1	1	48.9	2.073	1	1
39	55.3	3.079	1	1	49.0	2.088	1	1
40	55.5	3.101	1	1	49.1	2.102	1	1
41	55.6	3.122	1	1	49.2	2.115	1	1
42	55.7	3.140	1	1	49.2	2.127	1	1
43	55.8	3.157	1	1	49.3	2.137	1	1
44	55.9	3.173	1	1	49.4	2.147	1	1
45	55.9	3.187	1	1	49.5	2.156	1	1
46	56.0	3.200	1	1	49.5	2.164	1	1
47	56.1	3.212	1	1	49.6	2.171	1	1
48	56.1	3.223	1	1	49.6	2.178	1	1
49	56.2	3.233	1	1	49.7	2.184	1	1
50	56.2	3.242	1	1	49.7	2.190	1	1

Appendix 16: Parameter values used in the 2013 south Otago offshore strata SPR analyses.

	Males				Females			
Age	Length (cm)	Weight (kg)	Selectivity	Maturity	Length (cm)	Weight (kg)	Selectivity	Maturity
1	11.1	0.018	0	0	11.2	0.019	0	0
2	16.0	0.059	0	0	15.3	0.051	0	0
3	20.4	0.128	0	0	18.9	0.101	0	0
4	24.2	0.221	0	0.1	22.1	0.166	0	0.1
5	27.6	0.335	0	0.4	25.0	0.244	0	0.4
6	30.6	0.463	1	0.7	27.5	0.332	0	0.7
7	33.1	0.600	1	1	29.7	0.425	0	1
8	35.4	0.742	1	1	31.7	0.522	1	1
9	37.4	0.883	1	1	33.5	0.620	1	1
10	39.2	1.022	1	1	35.0	0.717	1	1
11	40.7	1.156	1	1	36.4	0.811	1	1
12	42.1	1.282	1	1	37.6	0.901	1	1
13	43.2	1.401	1	1	38.7	0.986	1	1
14	44.3	1.511	1	1	39.7	1.066	1	1
15	45.2	1.613	1	1	40.5	1.141	1	1
16	46.0	1.706	1	1	41.3	1.210	1	1
17	46.7	1.791	1	1	41.9	1.273	1	1
18	47.3	1.867	1	1	42.5	1.332	1	1
19	47.8	1.936	1	1	43.0	1.385	1	1
20	48.3	1.998	1	1	43.5	1.433	1	1
21	48.7	2.054	1	1	43.9	1.476	1	1
22	49.1	2.103	1	1	44.3	1.516	1	1
23	49.4	2.148	1	1	44.6	1.551	1	1
24	49.7	2.187	1	1	44.9	1.583	1	1
25	50.0	2.222	1	1	45.1	1.612	1	1
26	50.2	2.253	1	1	45.4	1.638	1	1
27	50.4	2.280	1	1	45.6	1.661	1	1
28	50.5	2.304	1	1	45.7	1.682	1	1
29	50.7	2.326	1	1	45.9	1.700	1	1
30	50.8	2.345	1	1	46.0	1.717	1	1
31	50.9	2.361	1	1	46.2	1.731	1	1
32	51.0	2.376	1	1	46.3	1.744	1	1
33	51.1	2.389	1	1	46.4	1.756	1	1
34	51.2	2.400	1	1	46.5	1.766	1	1
35	51.2	2.411	1	1	46.5	1.775	1	1
36	51.3	2.419	1	1	46.6	1.784	1	1
37	51.4	2.427	1	1	46.7	1.791	1	1
38	51.4	2.434	1	1	46.7	1.797	1	1
39	51.4	2.440	1	1	46.8	1.803	1	1
40	51.5	2.445	1	1	46.8	1.808	1	1
41	51.5	2.450	1	1	46.8	1.813	1	1
42	51.5	2.454	1	1	46.9	1.817	1	1
43	51.6	2.458	1	1	46.9	1.820	1	1
44	51.6	2.461	1	1	46.9	1.824	1	1
45	51.6	2.464	1	1	46.9	1.826	1	1
46	51.6	2.466	1	1	47.0	1.829	1	1
47	51.6	2.468	1	1	47.0	1.831	1	1
48	51.6	2.470	1	1	47.0	1.833	1	1
49	51.7	2.472	1	1	47.0	1.835	1	1
50	51.7	2.473	1	1	47.0	1.836	1	1